1979

Quaternary geology and stratigraphy of Kitsap County, Washington

Jerald D. Deeter
Western Washington University, jerrydeeter@comcast.net

QUATERNARY GEOLOGY AND STRATIGRAPHY OF KITSAP COUNTY, WASHINGTON

by

Jerald D. Deeter

Accepted in Partial Completion

of the Requirements for the Degree

Master of Science

[redacted]

Dean of Graduate School

ADVISORY COMMITTEE

[redacted]

Chairperson

[redacted]

[redacted]

MASTER'S THESIS

Jerald D Deeter
April 8, 2015

ABSTRACT

New radiocarbon dates and stratigraphic evidence indicate correlations between stratigraphic units on Whidbey Island and in Kitsap County. Eight new C^{14} dates and five previous dates, together with the stratigraphic position of units and similarities in their composition, support the concept that the Double Bluff Drift, Whidbey Formation, and possibly Possession Drift, extend south of Whidbey Island into Kitsap County.

In Kitsap County, fine-grained floodplain deposits of the Whidbey Formation, with radiocarbon dates beyond the limits of conventional laboratory methods, are located at higher elevations than adjacent floodplain deposits of the Olympia nonglacial interval. This stratigraphic relationship suggests that the Whidbey floodplain was extensively eroded prior to deposition of the Olympia floodplain sediments which are unconformable upon this irregular surface. Thus, Molenaar's belief that the Kitsap Formation was deposited during the Olympia nonglacial interval and his useage of the term Kitsap Formation for these stratified fine-grained sediments of various ages, is incorrect.

The type locality of the Kitsap Formation, near Maplewood in southeast Kitsap County, includes a silt and two thin peat units lying between oxidized gravel of a pre-Vashon glaciation that is overlain by fine-grained Olympia sediments. Molenaar interpreted this sequence as a transition from glacial to nonglacial deposition

and included the silt, peat, and oxidized gravel in the Kitsap Formation. However, a recent C^{14} date obtained from the peat was >40,000 yrs B.P. (WW), whereas the oldest C^{14} date obtained by the author from Olympia sediments elsewhere in Kitsap County is 36,235 yrs B.P. (U.W. 446). In addition, the arbitrary contact chosen by Molenaar between glacial and nonglacial sediments at Maplewood is not representative of the contact elsewhere in Kitsap County, and by including the oxidized gravel as part of the Kitsap Formation, he has deviated from the fine-grained nonglacial description originally used in defining the Formation.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF PLATES

QUATERNARY GEOLOGY AND STRATIGRAPHY OF KITSAP COUNTY, WASHINGTON

INTRODUCTION

Since investigations of Pleistocene geology in the Puget Lowland began near the turn of the century, names for various glacial and non-glacial deposits have been changed and new names added. New information on Pleistocene geology in the Lowland is now available from radiocarbon dates, pollen analysis, petrologic-mineralogic studies, stratigraphic correlations, relative sea level changes, and geologic mapping. This study of Kitsap County geology incorporates new data for use in correlating stratigraphic units with those of adjacent areas in the Puget Lowland.

Location and Geologic Setting

The study area (Figure 1) includes all of Kitsap County. Seventeen 7½ minute U. S. Geological Survey topographic Quadrangle maps (Figure 1) were used as base maps for geologic mapping and for preparation of slope stability maps.

Kitsap County occupies the northern portion of the Kitsap Peninsula, Bainbridge Island, and Blake Island (Figure 1). The county lies within a long north-south trending structural and topographic lowland, bordered by the Cascade Mountains on the east and the Olympic Mountains on the west. Marine waters surround the county on three sides: Hood Canal to the west, Admiralty Inlet to the north, and Puget Sound and Colvos

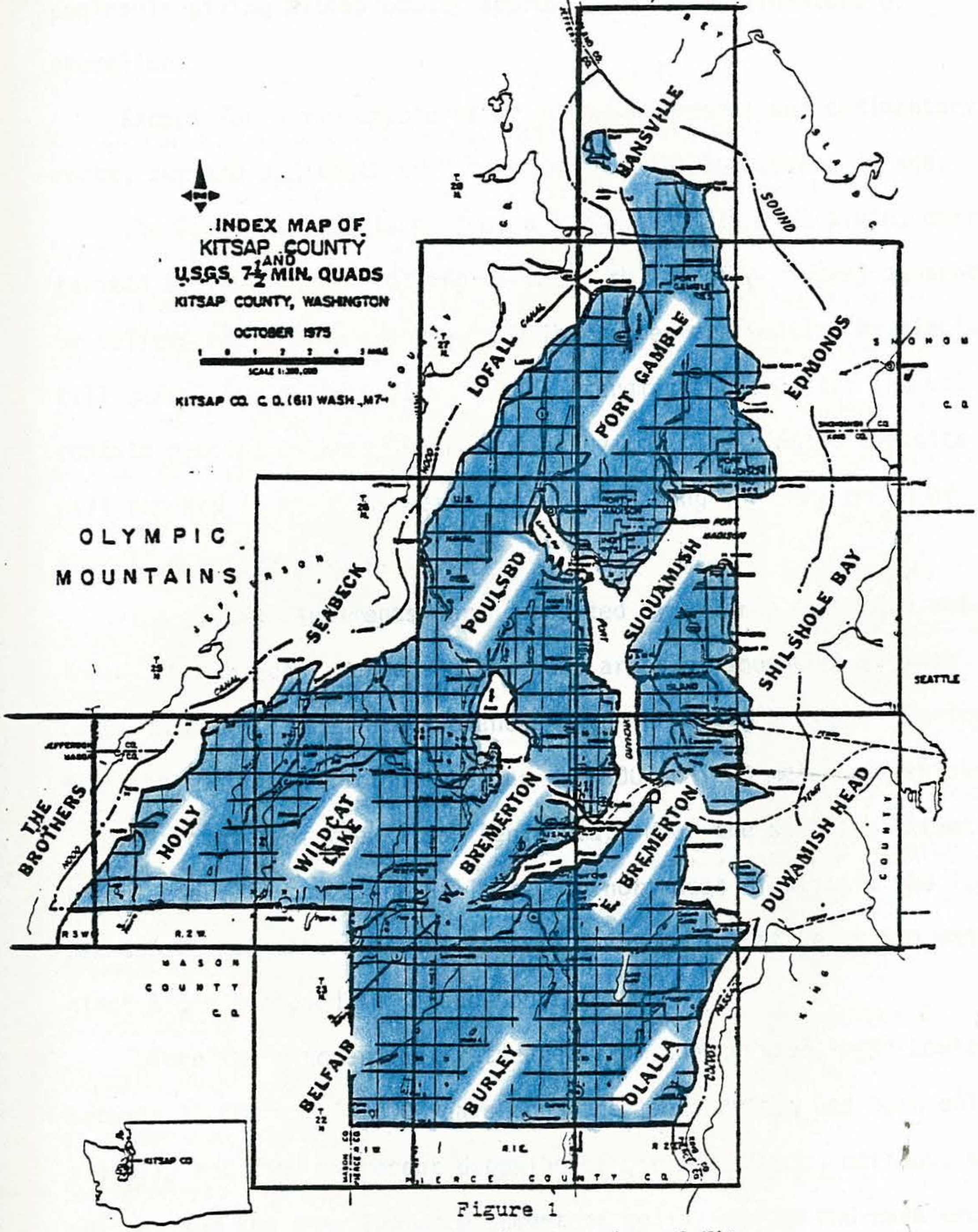


Figure 1
Index map showing location of Kitsap County and U.S.G.S. 7½ minute topograhic Quadrangles involved in study area.

Passage to the east. In addition, many marine embayments indent the peninsula giving Kitsap County approximately 365 kilometers of shoreline.

Except for a few exposures of Tertiary igneous and sedimentary rocks, surface sediments of Kitsap County are Pleistocene in age.

The Puget Lowland is part of a large glacial drift plain, characterized by low, gently rolling north-south trending ridges, separated by valleys and marine embayments. The ridges are mantled by glacial till underlain by older glacial and interglacial deposits; the valleys contain glacial outwash and recent alluvium. The glacial deposits are well exposed in numerous sea cliffs found along the many miles of shoreline in the county.

The glacial sediments were deposited by a large ice sheet which formed in the Coast Range and adjacent areas of southwest British Columbia and made repeated advances into the Puget Lowland. During the last major glaciation, the ice was 900 to 1200 meters in thickness in the vicinity of the Kitsap Peninsula. Near the southern extent of the glacier, in the Black Hills region northwest of Olympia the ice was 360 to 600 meters in thickness. Evidence for at least two major glaciations is found in Kitsap County.

Since the glacier last retreated from the central Puget Lowland between 13,000 and 14,000 years ago, the land surface has been only slightly modified by recent deposits of streams, lakes, marshes, small deltas, and the sea; the development of soils; stream and wave erosion; and landslides.

Purpose

The principle focus of this thesis is the Pleistocene stratigraphy of Kitsap County. The major question posed is whether the nonglacial Kitsap Formation is a viable rock-stratigraphic unit.

The Kitsap Formation was initially defined by Sceva (1957) and later redefined by Molenaar (Garling and others, 1965) on the Kitsap Peninsula as a nonglacial unit of the Olympia Interglaciation which ranged from 20,000 to over 40,000 years B.P.. The basis for assigning the Kitsap to this interval were radiocarbon dates of between 20,000 and 35,000 years B.P. obtained in the Puget Lowland. Since Molenaar named the Kitsap Formation, however, discrepancies in these early C^{14} dates due to tritium contamination have been found. More recent C^{14} dates, from the same localities as previously dated samples, have all been beyond the limits of conventional C^{14} dating. In addition, Armstrong and others (1965) originally assigned the rank of interglaciation to the Olympia interval that immediately preceded the Vashon Stade of the Fraser Glaciation in the Puget Lowland. The Olympia has now been redefined by Hansen and Easterbrook (1974) as a nonglacial interval of less than interglacial ranking. New radiocarbon and palynological data suggest that the time interval represented by the Olympia nonglacial interval is shorter than previously believed, with an older age limit between 28,000 and 35,000 years B.P. (Hansen and Easterbrook, 1974; Heusser, 1972). If this limit is correct, then questions arise about the age and definition of the Kitsap Formation. Does all or part of the Kitsap Formation belong to a pre-Olympia non-glacial or glacial lacustrine interval, or did the Olympia nonglacial interval extend to early Wisconsin time without interruption? The answers to the above questions can be determined from study of the stratigraphy of Kitsap County.

The second portion of this thesis is an applied section which includes a surficial geology, on-site sewage feasibility map and a slope stability map for the county. These maps are based on field work in 1975, 1976, 1977, and the first quarter of 1978, and also on work by Sceva (1957) and Molenaar (Garling and others, 1965).

Previous Work

Most of the early work in the Puget Lowland, which began in the 1890s, was spent in interpreting the overall extent of glaciation in the Puget Lowland and did not concentrate specifically on the Kitsap Peninsula. I. C. Russell (whose notes on this region were never published) first recognized two till sheets separated by stratified sand, gravel and peat along the sea cliffs of Admiralty Inlet. Bailey Willis (1898) named the lower deposits, consisting of till and stratified material, the Admiralty sediments and assigned the overlying sand, gravel and peat to the Puyallup Interglaciation. The upper till was named Vashon by Willis (Table I). J Harlan Bretz (1913) extended the terms Admiralty and Vashon to most of the Puget Lowland and established a general glacial history.

The first soils study for Kitsap County was published by Wildermuth and others (1939). An updated soil survey (M_cMurphy and Ping, in press) has been recently completed.

Geologic studies of Kitsap County were made by Sceva (1957) and

Table 1

Summary of Previous Stratigraphic Units in Kitsap and Island Counties

Willis 1898 Bretz 1913	Sceva 1957	Molenaar 1965	Easterbrook 1968 (Whidbey Island)
Vashon Glacial	Vashon Drift	Vashon Drift	Vashon Drift
Puyallup Interglacial	Puyallup Sand	Colvos Sand	Esperance sand
		Unnamed Gravel	
	Orting Gravel: a. Upper Kitsap Clay Member	Kitsap Formation	Quadra Formation
Admiralty Glacial	b. Lower Member	Salmon Springs (?) Drift	Possession Drift
	Admiralty Drift	pre-Salmon Springs (?) Deposits, Undifferentiated	Whidbey Formation
			Double Bluff Drift

Molenaar (Garling and others, 1965). Sceva's (1957) geologic sequence (Table 1) consisted of Admiralty Drift overlain by the Orting Gravel, which he divided into a lower member and upper, Kitsap clay member. The Kitsap clay member is overlain by Puyallup sand and Vashon Drift. Molenaar (Garling and others, 1965) drastically modified Sceva's sequence. Molenaar's sequence (Table 1) consisted of (from oldest to youngest) pre-Salmon Springs deposits, Salmon Springs Drift, Kitsap Formation, an unnamed gravel unit, and Vashon Drift.

The Pleistocene stratigraphy developed by Easterbrook (Easterbrook and others, 1967; Easterbrook, 1968) on Whidbey Island is considered here because of correlations made between units on Whidbey Island and those in Kitsap County. Easterbrook's geologic sequence (Table 1) consisted of Double Bluff Drift overlain by the interglacial Whidbey Formation, Possession Drift, Quadra Formation, Esperance sand, and Vashon Drift.

Acknowledgments

Special thanks are given to Kurt Othberg and Jerry Thorsen of the Department of Natural Resources, Geology Division, for their field advice, assistance in arranging funding of radiocarbon dates, and for their assistance in initiating the project.

Appreciation is extended to Al Zulauf of the U. S. Department of Agriculture, Soil Conservation Service, Bellevue office, for his effort in obtaining an updated soil and geology study for the county and also for his field assistance with soils.

The author also thanks the following individuals: Don J. Easterbrook, Western Washington University, who provided field assistance, advice, and guidance for the project; Chris Suczek and Andre Lehré, Western Washington University, for critical review of the thesis; Robert J. Carson, Whitman College, for providing field assistance, maps, and cross-sections; and Mackey Smith, Robinson and Noble Groundwater Geologists, Tacoma, Washington, for providing field advice.

A portion of this project was financed through a federal comprehensive planning grant from the Department of Housing and Urban Development authorized by Section 701 of the Housing Act of 1954, as amended. Slope stability and geology mapping along Kitsap County shorelines was accomplished through a Department of Ecology contract with the Department of Natural Resources, Geology Division. The author wishes to thank these agencies for their assistance.

Appreciation is extended to Dean Blout, Department of Community Development, Kitsap County, who coordinated and obtained grant money for the project.

Thanks are extended to Joe Wiegel, Director of Environmental Health for the Bremerton-Kitsap County Health District for his encouragement in undertaking the project and for allowing me to devote time to field work while employed at the Health Department.

STRATIGRAPHY OF KITSAP COUNTY

Introduction

Except for several isolated exposures of Tertiary igneous and sedimentary rocks, the stratigraphy of Kitsap County consists almost entirely of glacial and interglacial deposits of the Quaternary Period. To make the stratigraphic sequence for the county complete, the Tertiary deposits have been included in this report. The lower Pleistocene stratigraphy for Kitsap County is believed by the author to be correlative with that of Easterbrook and others (1967) on Whidbey Island. Evidence is presented for Double Bluff Drift, Whidbey Formation, and Possession Drift of Easterbrook and others (1967) extending south of Whidbey Island into Kitsap County. Because of the closeness of the northern tip of Kitsap County to Whidbey Island, stratigraphic work was concentrated there. A continuous stratigraphic cross-section around the entire northern shoreline of Kitsap County is included in the appendix (Plate 5, p. 105; Plate 6, p. 119). Many of the sections are referred to in this report; those plates not referred to are included for continuity and understanding of stratigraphic relationships. A complete summary of the stratigraphic sequence is included (Table II) on the following page.

Table 2

SUMMARY OF STRATIGRAPHIC UNITS
IN KITSAP COUNTY

PERIOD	EPOCH		MAP SYMBOL	STRATIGRAPHIC UNIT		DESCRIPTION	MAXIMUM THICKNESS
QUATERNARY	HOLOCENE		Qps	Alluvium		Peat with some silt and clay included and frequently saturated due to environment of deposition.	3m
			Qa			(1) Medium to coarse-grained sand. (2) Fine-grained sand, silt, and clay.	
	PLEISTOCENE		Qvr	VASHON DRIFT	Recessional outwash	Deposits of mostly unconsolidated, sand and gravel on valley floors and in deltaic and ice contact deposits along valley walls.	3m
			Qvt		Till	Gray, compact glacial till. Composition and compaction variable.	20m
		Qsu -WHIDBEY, KITSAP, & VASHON SAND UNDIFFERENTIATED	Qve		Esperance sand	Gray to tan, fine to medium-grained sand with thin silt lenses in lower part of unit, grading upward into lenticular beds of coarse sand and granule-to-pebble size gravel.	40m
			Qvl		Proglacial lacustrine deposits	Finely bedded gray to tan lacustrine silt and clay. Varve deposits are also included.	10m
			Qs	Skokomish gravel		Oxidized pebble-to-cobble gravel. Stones of Olympic Mountain provenance, mostly basalt, slate, graywacke, and sandstone.	30m to 60m
QUATERNARY	PLEISTOCENE		Qk	Kitsap Formation		Interbedded fine-grained sand, silt, clay, and peat with some discontinuous lenses of gravel.	30m
			Qp	Possession Drift		Oxidized sand and gravel of northern provenance; in places, silts interbedded with fine sand, silt, and peat. Oxidized gravel of Olympic Mountain provenance with C^{14} dates beyond limits of conventional dating techniques are also included.	16+m
			Qw	Whidbey Formation		Interbedded fine-grained floodplain sand, silt, clay, and peat.	30m
			Qdb	Double Bluff Drift		Till and glaciomarine drift. Till is light to dark gray, unweathered. Glaciomarine drift contains whole shells and shell fragments.	30m
TERTIARY			Tb	Sedimentary Rock of Blakely Fm.		Steeply dipping (45° to 90°) conglomerate, sandstone, and shale, often fractured and jointed.	90m
			Tv	Tertiary Igneous Rock		Dark, fine-grained basalt often vesicular and amydaloidal. Diorite intrudes the basalt, is coarse-grained, contains large phenocrysts, and is light gray. Gabbro is dark green, contains plagioclase and pyroxene.	54m

Eocene Epoch

Igneous Rocks (Tv)

Description:

The oldest rocks exposed in Kitsap County are extrusive basalt and intrusive gabbro and diorite. Extensive basalt flows from fissures and cones erupted during the Eocene Epoch across a broad, northwest-southeast trending piedmont that occupied most of what is now western and southwestern Washington (Weaver, 1937).

The basalts are mostly fine-grained, dark in color, and vesicular or amygdaloidal. They have been intruded by dikes and sills of gabbro and diorite with some alteration along contact zones.

The diorite is coarse-grained, containing large light gray plagioclase phenocrysts (Figure 2). Long acicular hornblende crystals make up

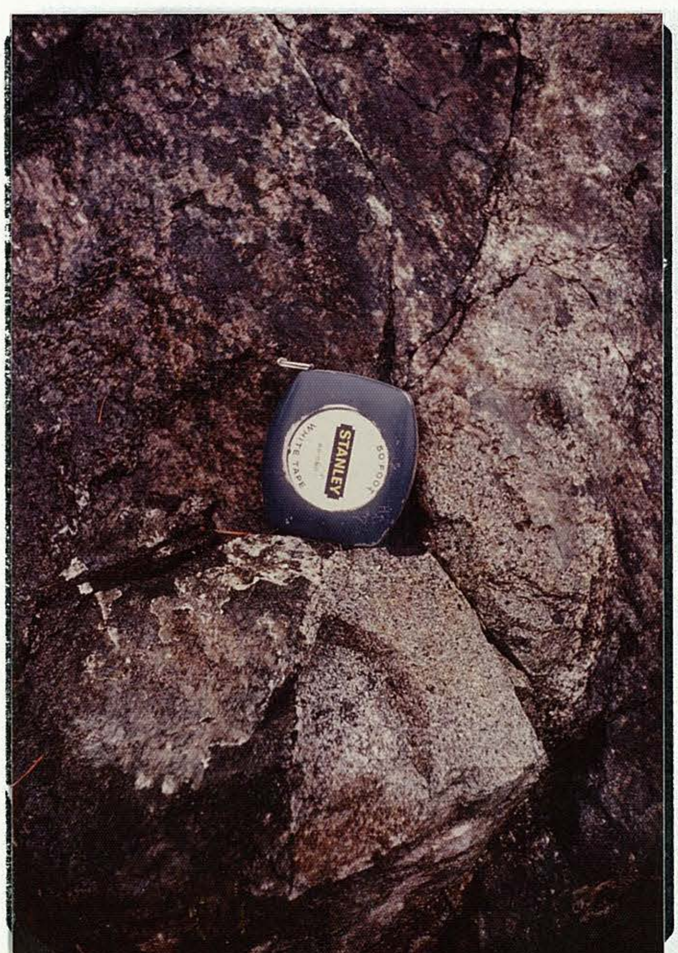


Figure 2. Coarse-grained diorite intruding gabbro at rock quarry west of Wildcat Lake in sec. 3, T. 24 N., R. 1 W.

25 to 30 percent of the rock. The gabbro is dark green, medium-grained, and contains plagioclase and pyroxene.

Distribution and Stratigraphic Relationships:

Basalt flows and intrusions of diorite and gabbro make up most of the Green and Gold Mountain areas which lie between Bremerton and Hood Canal. Gabbro, with dikes of diorite, is exposed along Green Mountain Road to the top of Green Mountain. Based on the extensive amount of intrusive gabbro observed in outcrops, the gabbro may form the central core of the Blue Hills. Crosscutting relationships indicate that the gabbro intruded the basalt and was later intruded by diorite. Where diorite has intruded the gabbro, some mineral alteration has taken place near the contact zone. The rock in this zone is decomposed and can be broken up easily by the soft blow from a hammer (Figure 3).

Figure 3. Contact zone adjacent to intrusion of diorite into gabbro at rock quarry west of Wildcat Lake in sec. 3, T. 24 N., R. 1 W.

Age:

Volcanic rocks on the Kitsap and Olympic Peninsula in Washington were correlated by Weaver (1937) with volcanic rocks on Vancouver Island, British Columbia, which were first described and named the Metchosin volcanics by Clapp in 1909. Although these rocks were first assigned a late Mesozoic Age by Clapp (1909), they were reassigned to the Eocene by Weaver (1937).

Oligocene Epoch

Blakely Formation (Tb)

Description:

After the volcanic and intrusive activity near the end of the Eocene Epoch, a thick sequence of conglomerate, sandstone, and shale composed mainly of volcanic detritus was deposited in shallow marine water. According to Weaver (1937), the total thickness of the Blakely Formation in Kitsap County is more than 2550 meters and its base is not exposed.

Much of this rock is fractured and steeply dipping (Figure 4). Weathering has formed residual soils on the Blakely rocks; soils are shown on the geologic map where their thickness is greater than one meter (Plate 7 in map pocket).

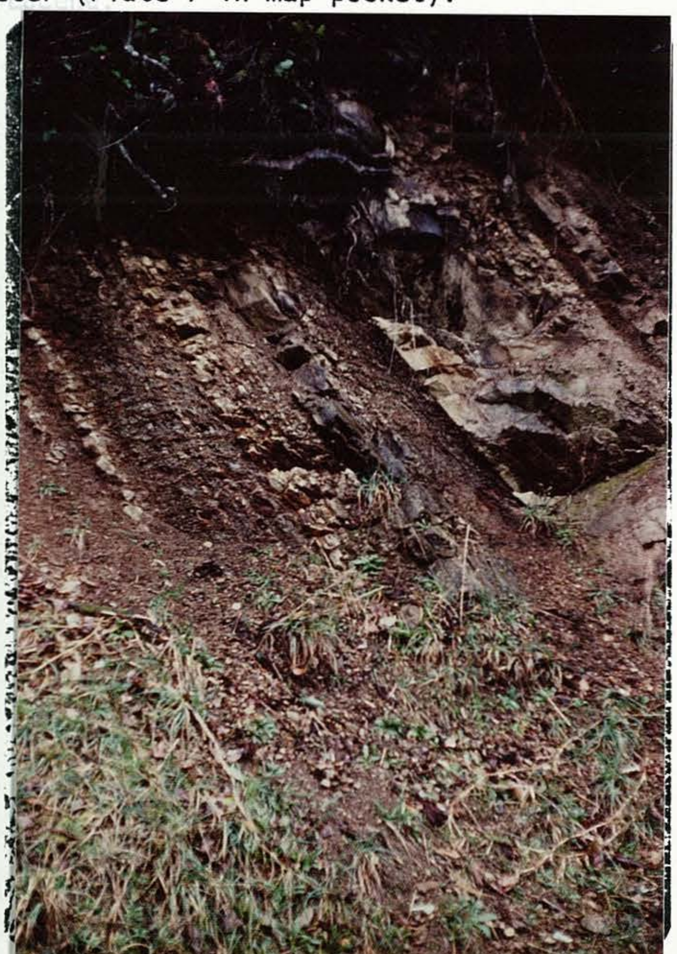


Figure 4. Steeply dipping sedimentary sandstone, shale, and conglomerate of the Blakely Formation at Watauge Beach in sec. 9, T. 24 N., R. 2 E.

Distribution and Stratigraphic Relationships:

The Blakely Formation is exposed on the south end of Bainbridge Island, on the mainland south of Rich Passage, at Rocky Point near Bremerton, and on the east side of the Port Washington Narrows (Plate 7 in the map pocket).

The Blakely Formation is overlain by Vashon Drift with a marked angular unconformity; its base is not exposed.

Age:

The Blakely Formation was described and named by Weaver (1912) who later determined its age as Oligocene based on its fossil assemblage. A more recent study of foraminifera by Fullmer (1975) indicates the Blakely belongs to the Zemorian stage of the Oliogene with a small portion of the base belonging to the Refugian stage of the uppermost Eocene.

QUATERNARY PERIOD

Pleistocene Epoch

Double Bluff Drift (Qdb)

Description and Lithology:

The oldest glacial drift recognized by Easterbrook and others (1967; Easterbrook, 1968; Easterbrook, 1969) in the Puget Lowland between Seattle and British Columbia is the Double Bluff Drift. The type section of the drift is in sea cliff exposures at Double Bluff, Whidbey Island, where it consists of gravel, till, sand, and glaciomarine drift (Easterbrook and others, 1967). Easterbrook and others (1967) concluded that the drift on Whidbey Island was not of great antiquity due to little or no weathering of pebbles in the drift and absence of weathering profiles at the top of the unit. Radiocarbon dates from material directly overlying the Double Bluff unit are beyond the limits of conventional C^{14} dating techniques (Easterbrook, 1968).

The oldest glacial drift recognized in Kitsap County is tentatively correlated with the Double Bluff Drift on Whidbey Island. Thickness of the drift in Kitsap County ranges from several meters to a maximum of 30 meters. The till ranges in color from gray to dark gray and is mostly unweathered or only slightly oxidized on its outer surface. Glaciomarine drift, consisting of diamictons containing shell fragments or whole shells, is frequently found in the Double Bluff unit. The glaciomarine drift generally directly overlies the till. At several localities in the county, the unit consists of up to 4.9 meters of stony, deformed silty clay which Molenaar (Garling and others, 1965) mapped as pre-Salmon Springs undifferentiated sediments.

In most localities in Kitsap County, Double Bluff till is very difficult to differentiate from the younger Vashon till. Bretz (1913) noted that the character of Vashon till was similar to that of older tills and that granites of various kinds were as common in older tills as in Vashon till. He concluded that there were no essential diagnostic differences between the tills and identification must be based on stratigraphic relations. Fabric studies of the two tills show that till fabric has no significance in differentiating between them. Orientation of long axes of pebbles in Vashon till varied generally between N 10^{o} to 48^{o} W, with the majority between N 25^{o} to 45^{o}W. Most of the stones in the older till were aligned N 3^{o} to 88^{o} W with an average of N 38^{o} W. My studies show that till fabric has no significance in differentiating between Double Bluff and Vashon tills.

Distribution and Stratigraphic Relationships:

Correlation of the lower glacial drift unit found in Kitsap County with the Double Bluff till on Whidbey Island is based on the following criteria:

1. The lowermost till in Kitsap County and the Double Bluff tills on Whidbey Island are overlain by a thick sequence of Whidbey Formation sediments. The Possession Drift lies stratigraphically above the Whidbey Formation (Easterbrook and others, 1967) and, unlike the Double Bluff Drift, has a very limited section of Olympia nonglacial sediments overlying it. The Double Bluff and Possession Drifts are indistinguishable if Whidbey sediments are absent.

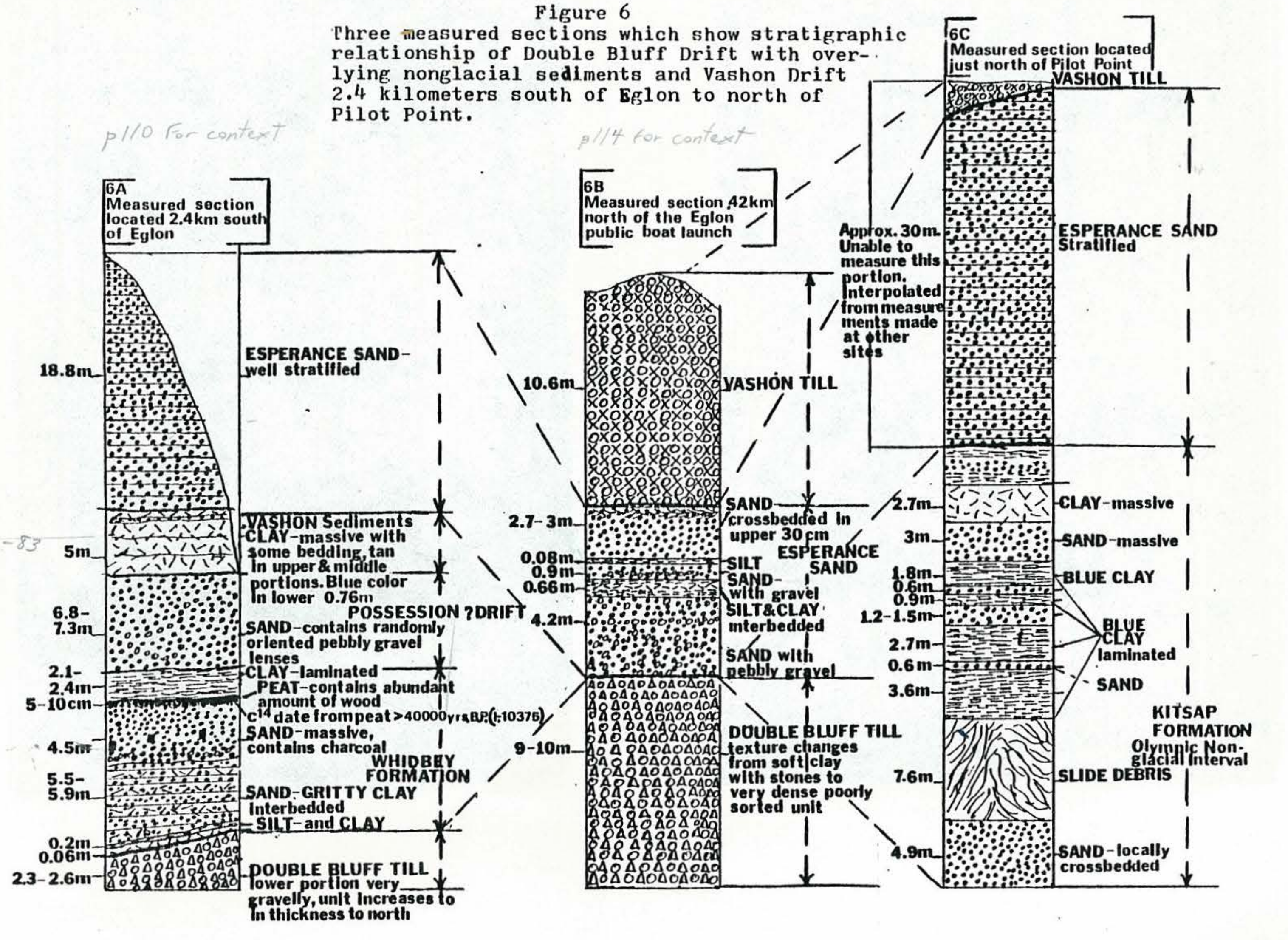
2. Both tills are dense, unweathered, gray to dark gray, contains clasts of the same provenance, and have associated glaciomarine deposits. Most known deposits of Double Bluff Drift occur near sea level with the base of the drift unexposed. However, since Vashon and Possession tills have similar characteristics, this relationship can only be used in conjunction with stratigraphic position.

Good exposures of the Double Bluff Drift are uncommon in Kitsap County. In the southern part of the county between Point Southworth and Olalla (Sec. 34, T. 23 N., R. 2 E.), Double Bluff till is exposed directly above the beach at several locations (Figure 5).

Double Bluff till is exposed 1.6 kilometers south of Eglon (sec. 11, T. 27 N., R. 1 E.) where it reaches a thickness of 30 meters (Plate 5.6, p. 110). The till decreases in thickness for 0.8 kilometers to the south where it disappears below sea level (Figure 6A).

Figure 5. Double Bluff till exposed at sea level near Anderson Point in sec. 34, T. 23 N., R. 2 E.

Figure 6
Three measured sections which show stratigraphic relationship of Double Bluff Drift with overlying nonglacial sediments and Vashon Drift 2.4 kilometers south of Eglon to north of Pilot Point.



19

Figure 7. Drag fold at base of Double Bluff Drift south of Eglon in sec. 11, T. 27 N., R. 1 E. Clay has been slightly overturned.

Figure 8. Vashon till overlies 7.6 m of Vashon advance outwash. Pebbly clay diamicton underlies the gravel and is believed to represent Double Bluff Drift. Sec. 2, T. 27 N., R. 2 E.

The base of the till unit at this locality is involved in a drag fold (Plate 5.6, p. 110; Figure 7, p. 20) with overturned clay rising several meters above sea level.

Double Bluff till is also exposed just north of the Eglon public boat Launch (sec. 2, T. 27 N., R. 3 E.) where the overlying Vashon till is separated from it by 7.5 meters of silt, sand, and gravel (Plate 5.8, p. 114; Figure 6B, p. 19; Figure 8, p. 20). The Double Bluff till at this locality contains a higher percentage of clay than elsewhere in Kitsap County. The higher clay content of the till, along with direct exposure to wave attack, make the unit very unstable.

Approximately 750 meters east of the pier at Indianola, a gravelly till believed to be Double Bluff Drift is exposed at sea level; here 6 meters of gravel overlie one meter of lodgement till (plate 1, page 22, Figure 9; Figure 10, p. 23).

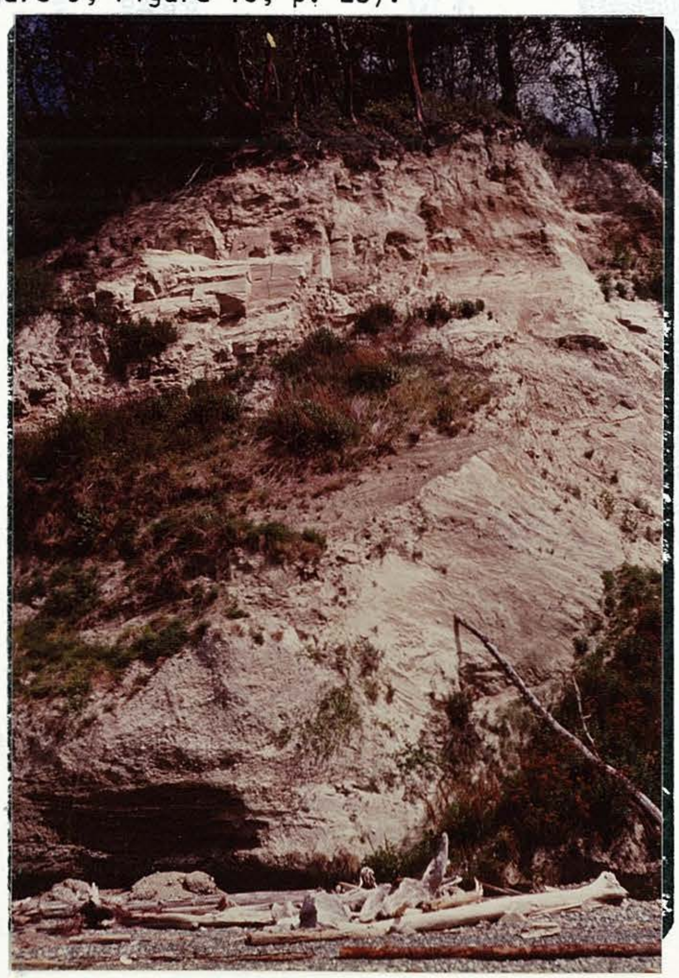


Figure 9. Double Bluff gravel and lodgement till overlain by organic tan silt and Vashon till in sec. 14, T. 26 N., R. 2 E.

Plate 1

Cross section that depicts stratigraphic relationship of Double Bluff Drift, Whidbey Formation, and Vashon Drift from Indianola pier east to church camp (A-B). Map location indicated on page .

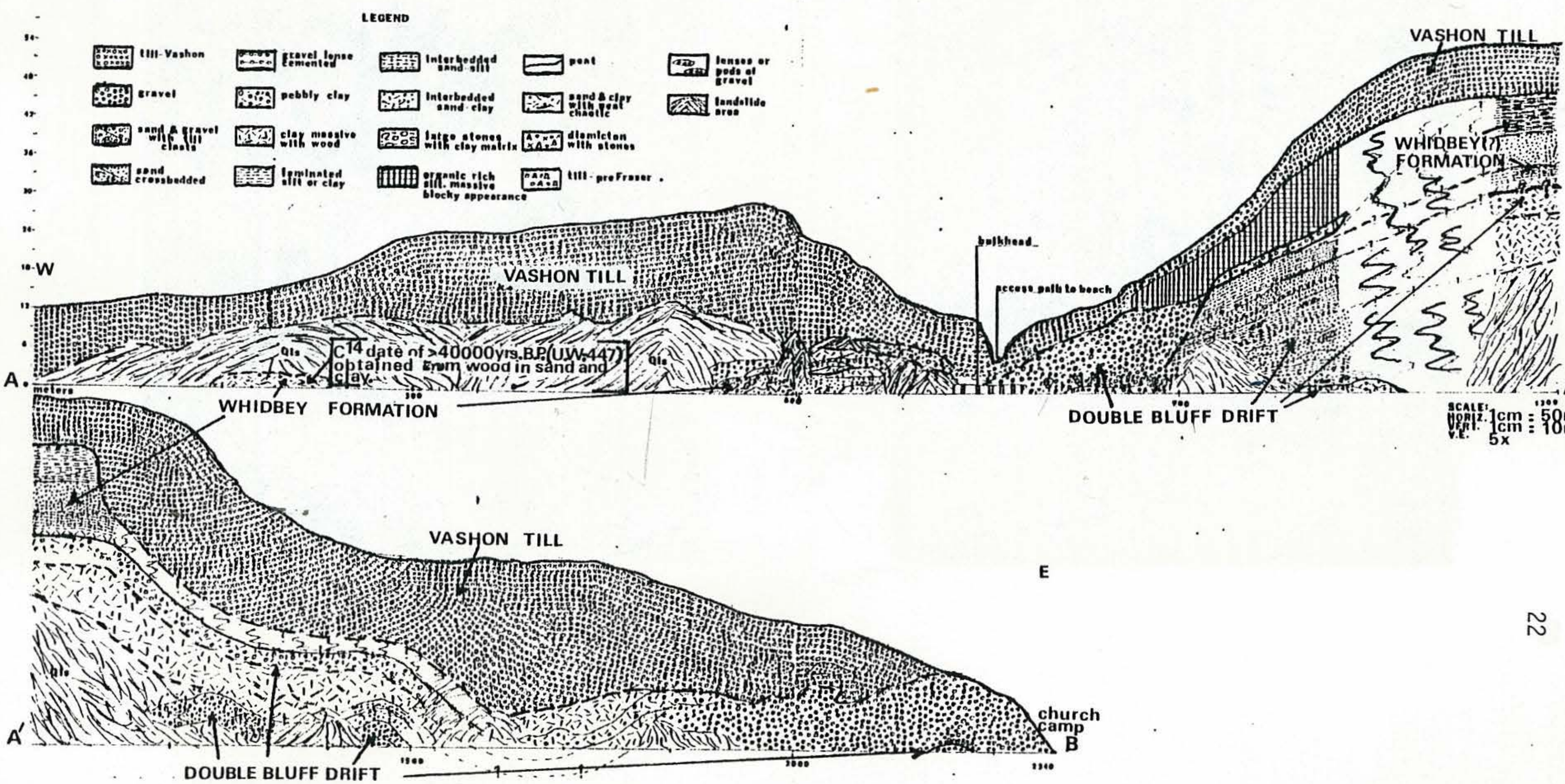


Figure 10. Gravel and lodgement till underlying interbedded silt, sand, pebbly clay, and till-like strata at Indianola in sec. 14, T. 26 N., R. 2 E.

Figure 11. Dated sample of >40,000 years B.P. (U.W. 447) obtained from fine sand and clay exposed just above sea level at Indianola in sec. 15, T. 26 N., R. 2 E.

The surface of the till is very irregular, and gravel with till clasts has been deposited upon the surface. Pebbly clay and thin till-like strata are interbedded with lenses of sand and blue clay. This unit interfingers with the lodgement till and gravel and is also thought to belong to the Double Bluff Drift. Although no shells or shell fragments have been found, much of this material is probably glaciomarine in origin. The only other explanation for the till-like strata is it represents flow till deposits.

The basal till unit at Indianola is mapped as part of the Double Bluff Drift because it is thought to stratigraphically underlie non-glacial deposits of the Whidbey Formation. Correlation of the nonglacial sediments to the Whidbey is based on a C^{14} date of >40,000 years (U. W. 447) obtained from wood collected by the author in these sediments (Plate 1, p. 22; Figure 11). The stratigraphic position between the dated unit and the Double Bluff till, which is first exposed 500 meters east of the dated section, is difficult, however, because major land-slides occurred during the winter of 1977 - 1978 and have completely covered most of the Whidbey Formation; thus a clearly defined contact between the Double Bluff Drift and Whidbey Formation is not found.

Double Bluff till, 7.6 meters thick observed at Foulweather Bluff (Plate 6.6, p. 124; Figure 12; Figure 13, p. 25) is overlain by two discontin-uous peat lenses and interbedded sand and clay. Above this, 2.8 to 3 meters of sand and oxidized pea-to-pebble-size gravel containing some diorite, granite and metamorphic rocks is thought to be Double Bluff recessional outwash. A diamicton containing whole shells and shell

Figure 12. Exposure of 7.6 m of Double Bluff till at Foulweather Bluff in sec. 12, T. 28 N., R. 1 E.

FIGURE 13
STRATIGRAPHIC SECTION FROM FOULWEATHER BLUFF

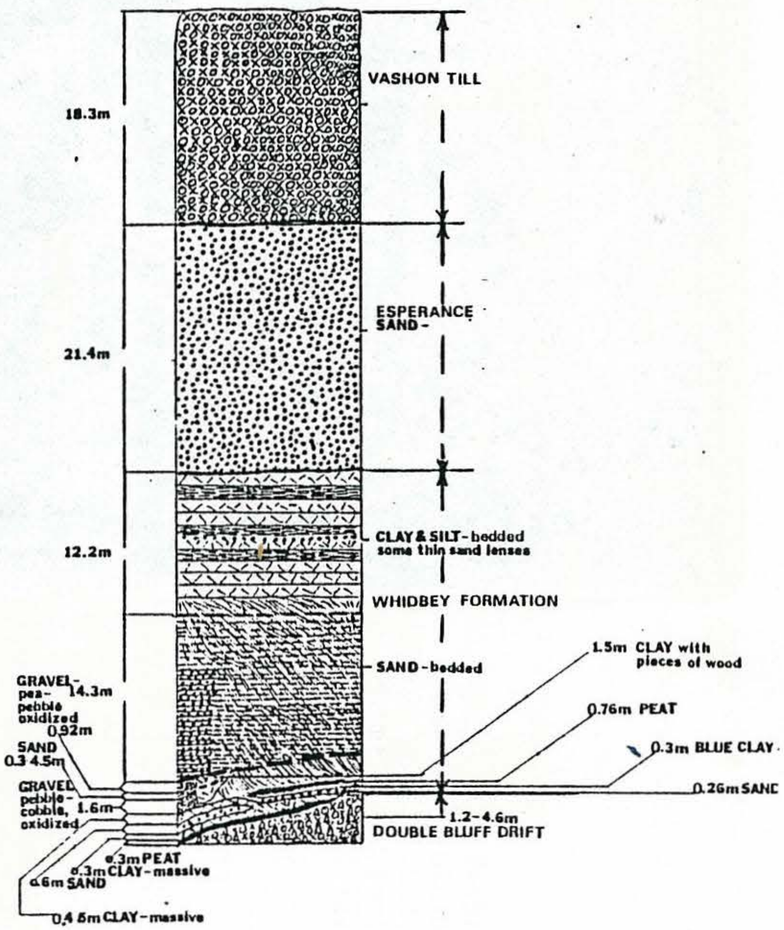


Figure 14. Pebbly clay diamicton containing whole shells and shell fragments at Foulweather Bluff in sec. 12, T. 28 N. R. 1 E.

fragments (Figure 14) overlies Double Bluff till approximately 60 meters to the east of the Foulweather Bluff exposure discussed above. Bretz (1913, p. 181) listed a number of marine organisms found within this unit (Plate 6.6, p. 124). Dr. Dall (Bretz, 1913), who identified the fossils, stated that all species found were living at present in the coldest waters of Puget Sound, and thence northward to the Arctic. Easterbrook (Easterbrook and others, 1967; Easterbrook, 1968) described similar glaciomarine drift in the same stratigraphic position at the Double Bluff type locality on Whidbey Island. Therefore, the Kitsap County unit is included here as part of the Double Bluff Drift.

Whole shells and shell fragments within stony clay diamictons at several other locations along the shorelines of Kitsap County are thought to be the same age as the Double Bluff Drift, but definite proof is lacking. Stony clay diamicton with shells are found one kilometer south of Foulweather Bluff near Twin Spits (sec. 12, T. 28 N., R. 1 E.); on the east side of Port Gamble Bay south of Little Boston (sec. 8 and 17, T. 27 N., R. 2 E) (Plate 6.16, p. 134; Plate 6.18, p. 136); and on the west side of Port Gamble Bay (sec. 8, T. 27 N., R. 2 E.). Pelecypod, gastropod, and cirriped (barnacle) fossils are found in pebbly glacio-marine silt and till-like deposits at Rolling Bay and at Fletcher Bay on Bainbridge Island (M. Smith, oral communication, 1978) (Figure 15). At Rolling Bay the diamicton is deformed. This diamicton was mapped by Molenaar (Garling and others, 1965) as pre-Salmon Springs undifferentiated deposits but is included here as part of the Double Bluff Drift.

Figure 15. Pebbly clay diamicton containing shell fragments of pelecypod, gastropod, and cirriped organisms found north of Rolling Bay in sec. 2, T. 25 N., R. 2 E.

Neither Molenaar (Garling and others, 1965) nor Sceva (1957) recognized glaciomarine deposits in their Salmon Springs Drift or Admiralty Drift, respectively.

A glaciomarine drift containing small fragments of marine shells is exposed in the low sea cliff at Skunk Bay (sec. 18, T. 28 N., R. 2 E.), southeast of Foulweather Bluff. These and similar deposits at Foulweather Bluff are considered to be the same age as the Double Bluff Drift. A glaciomarine deposit at Possession Point on Whidbey Island underlies Double Bluff till, and is similar in thickness, grain size, and color to the deposit at Skunk Bay (Figure 16).

Figure 16. Double Bluff lodgement till underlain by glaciomarine deposit which is similar to deposit at Skunk Bay. This is at Possession Point, Whidbey Island in sec. 20, T. 28 N., R. 3 E.

Very weathered, pea-to-pebble-size gravel one meter thick is exposed near Point Washington Narrows (sec. 14, T. 24 N., R. 1 E.) This gravel was described by Bretz (1913) as probably Admiralty and may correspond to the Double Bluff Drift of Easterbrook and others (1967) or it may be older. The gravel is so decayed that metamorphic and igneous pebbles could be carved with a knife and disintegrated when struck by a hammer. Pebbles are so heavily coated with iron oxide stain that distinguishing lithologies is impossible.

Oxidized gravel up to 12 meters thick, believed to be Double Bluff, dips southeast just northwest of the Manette Bridge (sec. 13, T. 24 N., R. 1 E.). It contains quartz, diorite, and granitic pebbles, many of them flat (Figure 17) and fine-grained, stratified sand clasts.

Figure 17. Extensive oxidized gravel consisting of abundant flat stones on west side of Port Washington Narrows below Manette Bridge in sec. 13, T. 24 N., R. 1 E.

Figure 18. Highly deformed pebbly clay diamicton south of Southworth in sec. 1, T. 23 N., R. 2 E.

A highly deformed, pebbly, massive blue-gray clay (Figure 18), exposed near sea level at Southworth has been included as Double Bluff. This was previously mapped by Sceva (1957) as Admiralty Drift, whereas Molenaar (Garling and others, 1965) mapped it as part of his pre-Salmon Springs deposit undifferentiated. Sceva attributed the deformation to overriding of the sediments by the Vashon glacier.

Pebbly massive blue-gray clay with some interbedded sand is exposed to a maximum of one meter above sea level south of Fragaria and at several locations south of Command Point. The pebbly clay is believed to correlate with the deformed pebbly clay at Southworth and was most likely a glaciomarine deposit laid down in advance of the ice that deposited the Double Bluff, and then deformed by subsequent overriding by this glacier.

Age and Correlation:

All radiocarbon dates from Double Bluff Drift and the Whidbey Formation have been beyond the limits of conventional C^{14} dating. Although the age of the Double Bluff is uncertain, two possible correlations have been suggested by Easterbrook (1969) with glacial units in the southern Puget Lowland: (1) with the lower of two tills of the Salmon Springs Glaciation (Figure 19A), or (2) within an older drift, perhaps belonging to the Stuck Glaciation (Figure 19B).

At the type locality of the Salmon Springs in the southern Puget Lowland, Stuiver and others (1978) C^{14} dated peat within 0.7 to 1.4 meters of nonglacial sediments interbedded between the upper and lower Salmon Springs Drift at 71,500 $^{+1700}_{-1400}$ years B.P.. If Possession and Double Bluff Drifts correlate with the upper and lower Salmon Springs Drift, the Whidbey would correlate with the nonglacial sediments interbedded between the two drifts at Salmon Springs. If this interpretation is correct, ice advanced into the Puget Lowland and retreated sometime prior to 71,500 years ago, thus correlating with an early Wisconsin or older glaciation. A nonglacial interval followed the early Salmon Springs Glaciation, allowing deposition of the intertill sediments. Readvance of Cordilleran ice took place sometime after 71,500 years ago; the ice retreated from the Puget Lowland between 28,000 and 35,000 years ago (Hansen & Easterbrook, 1974).

Several weaknesses lie with this first interpretation:

1. There is a substantial difference in thickness of deposits representing the nonglacial interval between the Whidbey Island and the Salmon Springs localities. Approximately 90

Figure 19A

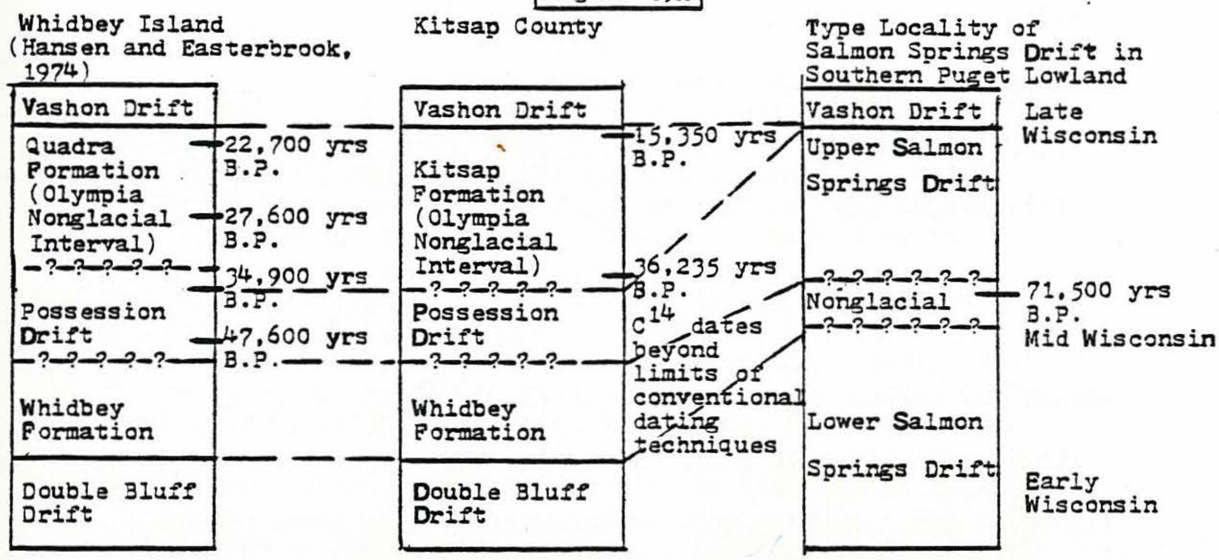
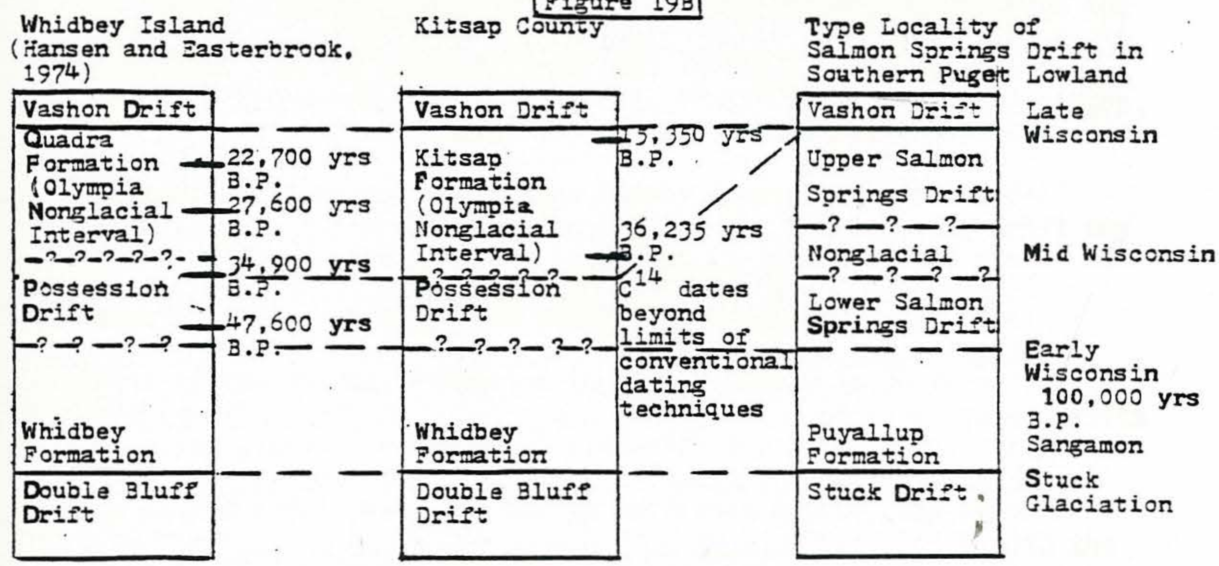


Figure 19B



Figures 19A and 19B are two interpretations of possible correlations of Double Bluff Drift on Whidbey Island and in Kitsap County with Salmon Springs Drift near Salmon Springs type locality in southern Puget Lowland.

meters of nonglacial sediment of the Whidbey Formation are exposed on Whidbey Island, whereas only 1.4 meters of non-glacial deposits are found interbedded between the two tills at Salmon Springs.

2. Nonglacial sediments are known to lie between the two tills of the Salmon Springs Glaciation near Sumner in the southeast Puget Lowland; pollen analysis from peat at that locality, although not conclusive, does not indicate any substantial interglacial interval within the Salmon Springs Drift (Easterbrook, 1969).
3. Evidence for a till in Kitsap County corresponding to Possession Drift on Whidbey Island and upper Salmon Springs Drift in the southern Puget Lowland is very sketchy. The only till that may represent this stratigraphic position is near Maplewood where an oxidized till of pre-Vashon age lies below a peat dated at >42,000 years B.P. (W-2028) (Marsters and others, 1969) (Table V, p. 59).

According to the second interpretation, the Double Bluff Drift may be correlative with the Stuck Drift (Easterbrook, 1969) and the interglacial Whidbey Formation may be correlative with the Puyallup Formation in the southeastern Puget Lowland. The upper and lower drifts at Salmon Springs may correspond to the Possession Drift on Whidbey Island. Much of the basis for correlating Double Bluff Drift with the Stuck Glaciation lies in similarities between the interglacial Whidbey and Puyallup Formations (Easterbrook, 1969).

Whidbey Formation

Description and Lithology:

The Whidbey Formation is named from deposits between Double Bluff and West Useless Bay on Whidbey Island (Easterbrook and others, 1967). It consists of horizontally stratified clay, silt, peat, sand and scattered lenses of gravel (Easterbrook and others, 1967). At its type locality and at many other sea cliff exposures, the Whidbey Formation lies upon Double Bluff Drift and is overlain by Esperance sand, but at several localities on Whidbey Island the Possession Drift lies between the Whidbey and Esperance (Easterbrook, 1969). Near the type locality, the Whidbey Formation is at least 60 meters thick (Easterbrook and others, 1967). According to Easterbrook and others (1967), the Whidbey Formation represents a nonglacial, floodplain deposit during a long interval in which glacial ice was absent from the Puget Lowland. Pollen analysis from peat in the Whidbey sediments suggests an interglacial climate that resembles that of the present.

The Whidbey Formation in Kitsap County consists of interbedded sand, silt, clay, and peat. Thin lenses of coarser sand and gravel are occasionally associated with the interbedded sediments. Maximum thickness of the Whidbey Formation in Kitsap County is 30 meters. The unit overlies glacial drift correlative with the Double Bluff Drift on Whidbey Island and is overlain mostly by Vashon Drift. The Whidbey Formation in Kitsap County represents a pre-Olympia interglacial floodplain that has been highly dissected by subsequent overriding by glaciers and by stream erosion.

Distribution and Stratigraphic Relationships:

The fine-grained floodplain deposits of the Whidbey Formation in Kitsap County have radiocarbon dates beyond the limits of conventional laboratory methods and are located at higher elevations than adjacent floodplain deposits of the Olympia nonglacial interval. This suggests that the Whidbey floodplain was extensively eroded, possibly by subsequent overriding during the Possession Glaciation, prior to deposition of the Olympia floodplain sediments which are unconformable upon this irregular surface. The lower contact of the Whidbey Formation lies unconformably upon the underlying Double Bluff Drift. Sediments of the Whidbey Formation in Kitsap County are, therefore, distinguished from similar Olympia nonglacial fine-grained sediments on the basis of the following criteria: (1) deposits yielding finite C^{14} dates are mapped as Olympia; (2) deposits beyond the range of conventional C^{14} dating techniques are mapped as Whidbey; (3) nonglacial sediments overlain by Possession Drift are mapped as Whidbey, based on stratigraphic position.

Exposures of the Whidbey Formation occur in a number of locations along the Kitsap Peninsula shoreline. South of Eglon, Whidbey sediments lie unconformably upon Double Bluff Drift and are overlain unconformably by proglacial lake sediments of Vashon Drift (Plate 5.6, p. 110; Figure 6A, p. 19). The Whidbey sediments consist of massive sand with thin lenses of gravel, laminated clay, peat, and interbedded gritty clay and sand. A date of $>$43,000 years B.P. in the Whidbey Formation (W-1578; Ives and others, 1967, p. 519) was obtained by Crandell from wood in the upper 15 meters of sand lying beneath proglacial clay and Esperance sand. Another C^{14} date of $>$40,000 (I-10,375) was obtained in the same unit from a woody peat sample collected by the author. The dated peat underlies laminated clay and sand from which the >43,000 year date was obtained. The differences in C^{14} dates result from interference caused by background radiation at different laboratories. Because of the age, the author has mapped these sediments as Whidbey, although some of these sands could possibly be part of the Possession Drift.

Two other dated sections from the Whidbey Formation are found near Indianola (sec. 14, T. 26 N., R. 2 E.) (Plate 1, p. 22; Figure 11, p. 23; Figure 20) and Fragaria (S.E. ¼, S.W. ¼, sec. 22, T. 23 N., R. 2 E.) Figure 22A. The C^{14} date of >40,000 years B.P. (U.W.-447) was obtained from wood (Figure 20) 0.5 meters above the beach at Indianola, in a tan, fine-grained sand. The dated unit is overlain by an unknown thickness of light gray silt. Approximately 400 meters east of the dated location is an exposure similar to the dated unit but without the light gray silt above it. Fine-grained sand and silt also overlie Double Bluff Drift farther east at Indianola (Figure 21). The nonglacial sediments at all three locations are believed to be correlative with the Whidbey Formation because of the C^{14} date and because they overlie Double Bluff till.

Along Fragaria Road near Fragaria, 22 meters of massive bedded clay containing two peat beds are overlain unconformably by Vashon Drift sand and gravel with the basal contact at this location unexposed. The upper peat is 0.6 to 0.76 meters thick; the lower peat is 1.0 to 1.4 meters thick (Figure 22A). A C^{14} date of >40,000 years B.P. (U.W.-450) was obtained from wood at the surface of the upper peat. Bretz (1913, p. 180) and Sceva (1957, p. 18) both describe this section in their reports. Bretz thought the peat was part of the Admiralty Drift.

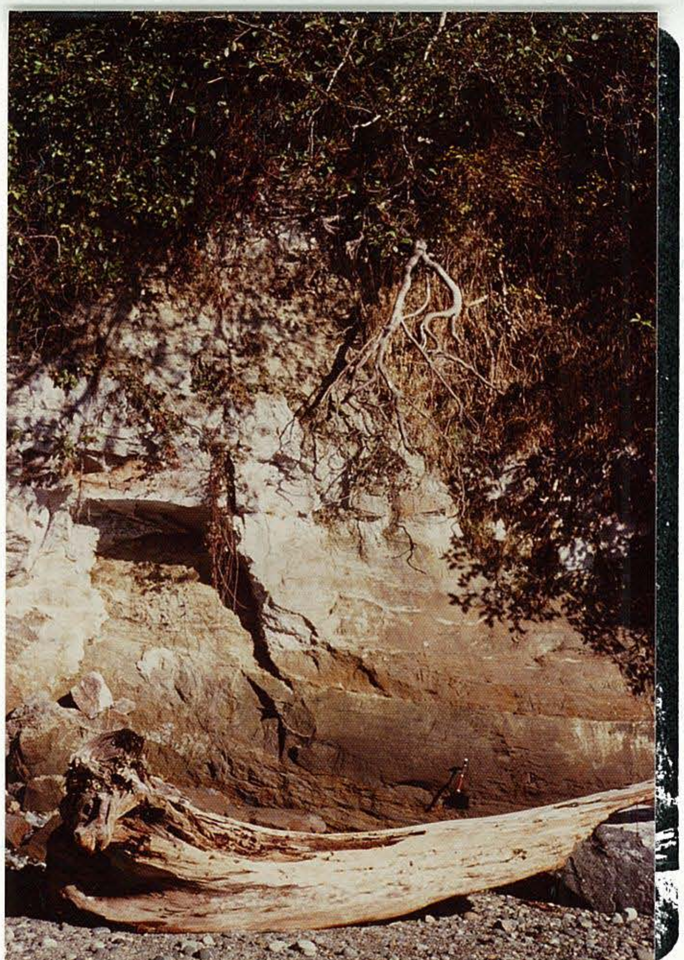


Figure 20. Dated sample (U.W.-447) obtained just below rock hammer in dense, fine-grained sand at Indianola section in sec. 15, T. 26 N., R. 2 E.

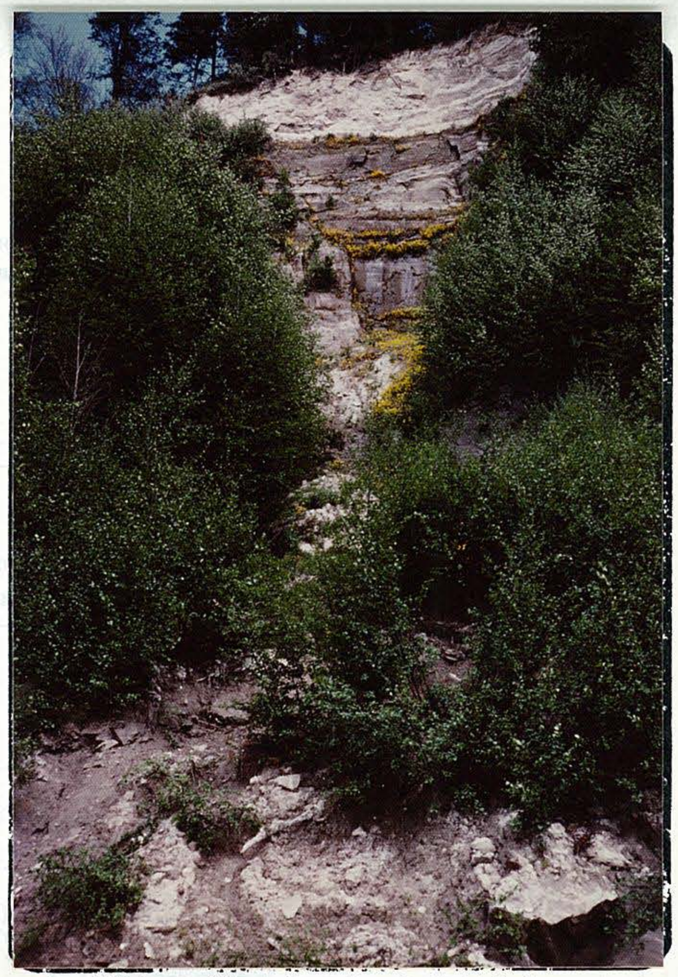
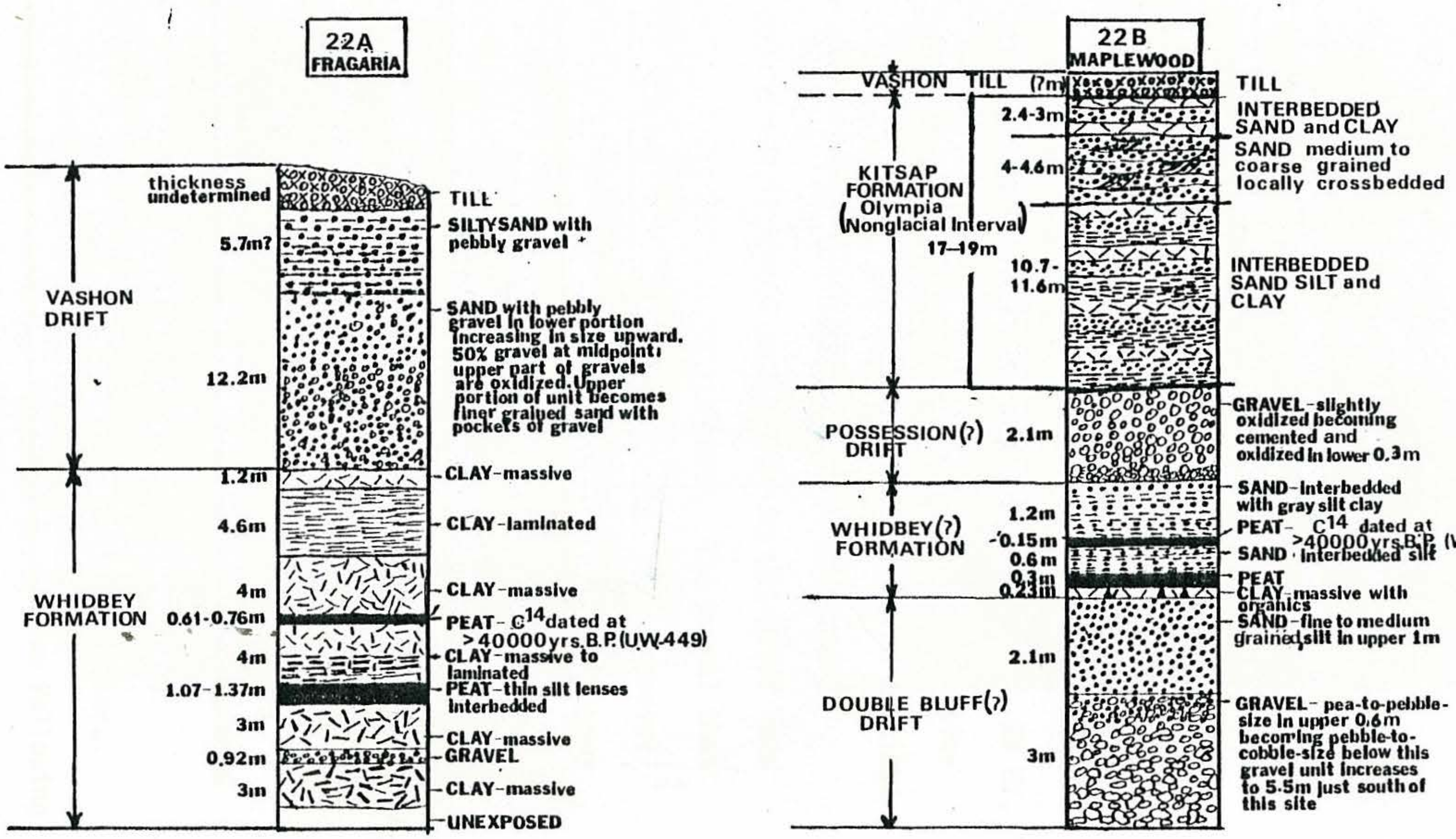


Figure 21. Nonglacial thinly bedded sand and silt separates overlying Vashon till from lower Double Bluff Drift near Indianola in sec. 14, T. 26 N., R. 2 E.

Figure 22 Two stratigraphic sections showing relationship of the Whidbey and Kitsap Formations to the Double Bluff(?), Possession(?), and Vashon Drift at Fragaria (sec. 22 T. 23 N., R. 2 E.) and 5.6 km south at Maplewood (sec. 9 T. 22 N., R. 2 E.) in Kitsap County.



Conclusive evidence is lacking as to whether certain exposures of nonglacial floodplain sediments in Kitsap County belong to the Whidbey Formation or to the Olympia. The stratigraphic relationship of the nonglacial sediments with pre-Vashon glacial sediments found close by, however, appears to place the floodplain deposits below the glacial unit; therefore, the nonglacial sediments are considered to be part of the Whidbey Formation or older and have been tentatively mapped as Whidbey sediments.

Nonglacial floodplain deposits which probably belong to the Whidbey Formation are exposed in a sea cliff along Rolling Bay (sec. 11, T. 25 N., R. 2 E.) and south of Murden Cove (sec. 23, T. 25 N., R. 2 E.) on Bainbridge Island. A C^{14} date of $>$40,000 years B.P. (U.W.-449) from oxidized gravel at Miller Road gravel pit, Bainbridge Island, is believed to indicate correlation with oxidized gravel exposed in the sea cliff less than 0.5 kilometers north of the Rolling Bay exposure. The gravel thus represents Possession Drift or an older drift and, although the gravel pinches out to the south, it is believed to lie stratigraphically above the floodplain deposits. The nonglacial sediments at Rolling Bay are believed to be the lateral equivalent of the fine-grained sediments at Murden Cove. Therefore, both nonglacial exposures are mapped tentatively as part of the Whidbey Formation.

Interbedded fine-grained, stratified sand, silt, and laminated clay, (Figure 23) thought to be part of the Whidbey Formation are exposed near Anderson Cove (sec. 8 and 17, T. 24 N., R. 2 W.). These were previously mapped as Kitsap Formation by Molenaar (Garling and others, 1965). The author disagrees with Molenaar's correlation for the following

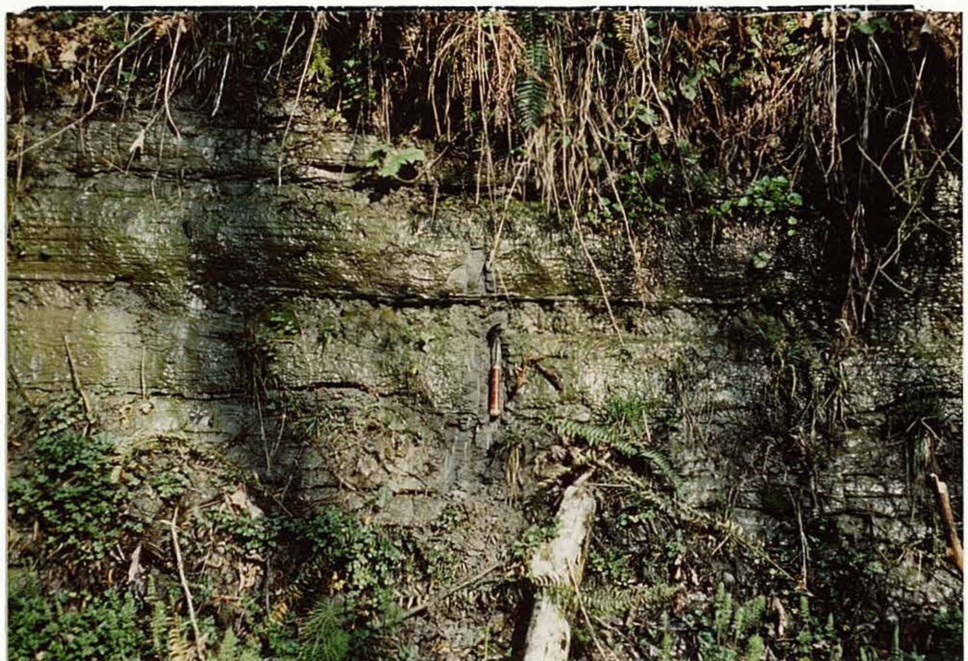


Figure 23. Interbedded silt and fine sand found in nonglacial deposit of Whidbey Fm. near Holly in sec. 17, T. 24 N., R. 2 W.

Figure 24. Thick unit of dense peat exposed above sea level on south side of Port Washington Narrows in sec. 11, T. 24 N., R. 1 E.

reason: Dense contorted clay, adjacent to the nonglacial sediments, was mapped as Colvos sand by Molenaar (Garling and others, 1965), but it appears to correspond to Possession Drift or an older drift as it lies at an elevation which would place the clay stratigraphically above the fine-grained deposits at Anderson Cove; therefore, the Anderson Cove unit is thought to correspond to the Whidbey Formation.

Floodplain sediments are exposed in a sea cliff along Port Washington Narrows 2.4 kilometers northwest of the Warren Avenue Bridge in west Bremerton. Clay, silt, and sand overlying 1.2 meters of peat (Figure 24) are believed to be of the Whidbey Formation because they are laterally equivalent with interbedded peat and clay that overlie weathered till previously discussed under Double Bluff Drift (page 29) and are stratigraphically overlain by oxidized gravel that may be correlative with Possession Drift. Although a C^{14} date has not been obtained in this particular peat, radiocarbon dates in peat units of equivalent thickness at Fragaria (Figure 22A, p. 38 ; Table 3, p. 44) and Southworth (Table 3, p. 44) have all been beyond the limits of conventional laboratory methods. In addition, peat deposits greater than 0.3 meters in Olympia nonglacial sediments have not been found. Thus, the peat and fine-grained sediments are included as part of the Whidbey Formation.

Several good exposures of fairly dense, laminated to massive clay occur west of Hansville (N.E. ¼, sec. 17, T. 28 N., R. 2 E.). The clay lies on an irregular surface of finely bedded, oxidized sand which is locally cross-bedded and, in some cases, contains a small percentage of pebble-size, granitic stones. The sand unit is probably correlative with a similar sand at Foulweather Bluff. A gravel unit, consisting of

QUATERNARY GEOLOGY AND STRATIGRAPHY OF KITSAP COUNTY, WASHINGTON

INTRODUCTION

Since investigations of Pleistocene geology in the Puget Lowland began near the turn of the century, names for various glacial and non-glacial deposits have been changed and new names added. New information on Pleistocene geology in the Lowland is now available from radiocarbon dates, pollen analysis, petrologic-mineralogic studies, stratigraphic correlations, relative sea level changes, and geologic mapping. This study of Kitsap County geology incorporates new data for use in correlating stratigraphic units with those of adjacent areas in the Puget Lowland.

Location and Geologic Setting

The study area (Figure 1) includes all of Kitsap County. Seventeen 7½ minute U. S. Geological Survey topographic Quadrangle maps (Figure 1) were used as base maps for geologic mapping and for preparation of slope stability maps.

Kitsap County occupies the northern portion of the Kitsap Peninsula, Bainbridge Island, and Blake Island (Figure 1). The county lies within a long north-south trending structural and topographic lowland, bordered by the Cascade Mountains on the east and the Olympic Mountains on the west. Marine waters surround the county on three sides: Hood Canal to the west, Admiralty Inlet to the north, and Puget Sound and Colvos coarse sand and slightly oxidized pebble- to-cobble-size stones, truncates the underlying laminated to massive clay (Plate 6.1, p. 105; Plate 6.2, p. 106). The gravel grades upward into stratified, medium- to coarse-grained sand. Granitic and metamorphic pebbles are dominant in the gravel. At least 2.7 meters of thinly laminated clay overlies the gravel and sand. The gravel is believed to represent recessional outwash of the Possession Drift with the overlying laminated clay deposited during the Olympia nonglacial period. The underlying clay and sand are, therefore, considered part of the Whidbey Formation.

The lower finely-bedded sand and clay unit described above is also exposed at Foulweather Bluff (N.E.¼, sec. 12, T. 28 N., R. 2 E.) where horizontally bedded sand and clay rests unconformably upon oxidized gravel of northern provenance. The gravel, which overlies till, is mapped as Double Bluff Drift. A thick sequence of medium-grained sand overlies the sand and clay unit. At present, the lateral equivalents of this thick sand unit are not known.

Many other exposures in Kitsap County may correspond to the Whidbey Formation, but because adequate sections, good contacts, and absolute dates are lacking, these units cannot be demonstrated to be part of the Whidbey. In cases where relative age cannot be determined, the units are mapped as undifferentiated nonglacial sediment (Qns).

Age:

Radiocarbon dates from the Whidbey sediments are all beyond the limits of conventional C^{14} dating. Dates obtained from Whidbey sediments in Kitsap County are listed in Table 3 (p. 44), and sample localities are shown in Figure 25 (p. 44). Easterbrook (1968; 1969) believes the

Whidbey Formation may correlate with the Puyallup Formation, and that both were probably deposited during the Sangamon Interglaciation which ended about 100,000 years B.P..

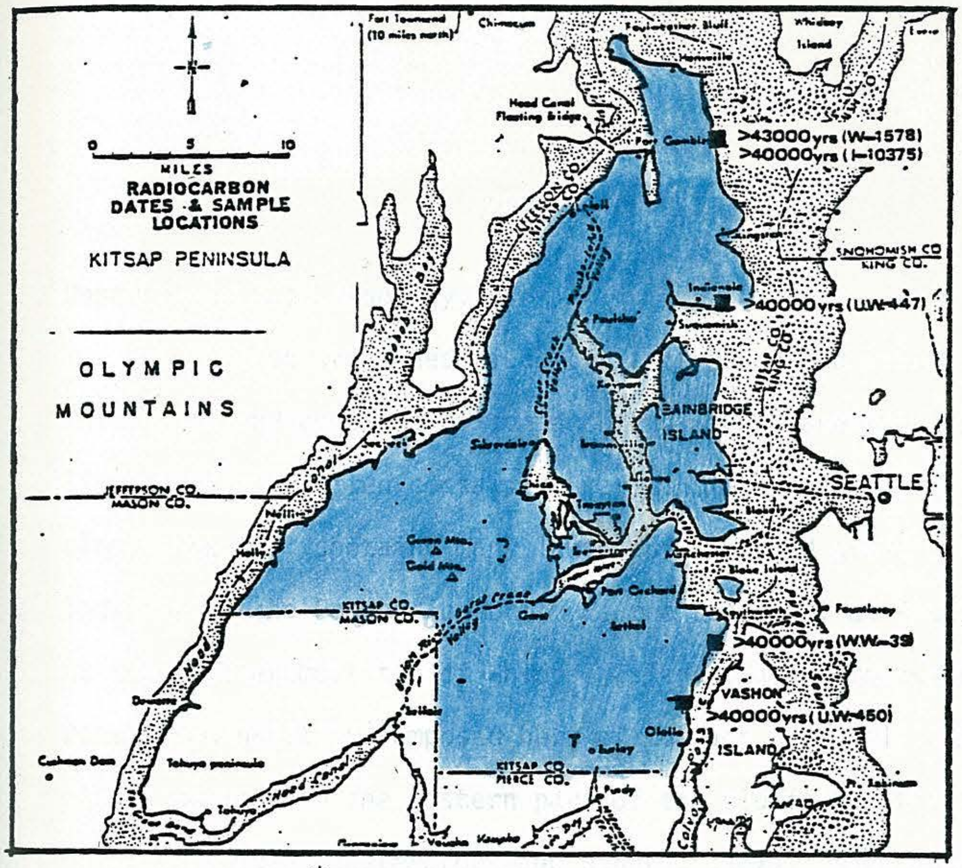


Figure 25. C^{14} dates sand sample localities in the Whidbey Formation.

Table 3

C^{14} DATES FROM THE WHIDBEY FORMATION IN KITSAP COUNTY

Date and Sample Number	Location	Source
>43,000 years B.P. (W-1578)	Eglon, Wash. S.W. ¼, N.E. ¼, sec. 11, T. 27 N., R. 2 E. Latitude: 47° 50' 50" N. Longitude: 122° 30' 20" W.	Sample from wood submitted by Crandell and thought to be from Olympia nonglacial interval; believed by the author to be Whidbey in age due to stratigraphic position and C^{14} date. Reference: Ives and others, 1967.
>40,000 years B.P. (I-10,375)	Eglon, Wash. S.W. ¼, N.E. ¼, sec. 11, T. 27 N., R. 2 E. Latitude: 47° 50' 50" N. Longitude: 122° 30' 20" W.	Woody peat lying below a laminated clay. The clay underlies massive tan sand and overlain by proglacial clay and Esperance sand.
>40,000 years B.P. (U.W.-447)	Indianola, Wash. S.E. ¼, N.E. ¼, sec. 15, T. 26 N., R. 2 E. Latitude: 47° 41' 49" N. Longitude: 122° 31' 10" W.	Wood collected from 2.5 m of thick, dark gray sand 0.5 m above beach. Overlain by light gray silt with Vashon till at top.
>40,000 years B.P. (WW-39)	Southworth, Wash. N.E. ¼, sec. 11, T. 24 N., R. 2 E. Latitude: 47° 40' 35" N. Longitude: 122° 30' 25" W.	Collected by D.J. Easterbrook and M. Smith. Previously dated at 34,000 (W-1437) by Crandell and Waldron (Levin and others, 1966). They described this as peat within fluvial and lacustrine silt, sand, and gravel of Olympia age. The author does not concur but believes this to be Whidbey Formation because of C^{14} date and stratigraphic position.
>40,000 years B.P. (U.W.-450)	Fragaria, Wash. S.E. ¼, S.W. ¼, sec. 22, T. 23 N., R. 2 E. Latitude: 47° 27' 41" N. Longitude: 122° 31' 10" W.	Upper of two peat beds interbedded with massive clay.

Possession Drift

Description and Lithology:

Possession Drift described by Easterbrook and others (1967) on Whidbey Island consists of compact sandy till, sand and gravel, and till-like stony clay often containing marine shells and shell fragments. In places the till contains many lenses of sand and gravel. The type locality of the Possession Drift is the sea cliff at Possession Point at the southernmost tip of Whidbey Island (Easterbrook and others, 1967). Possession Drift is composed here of compact gray till, 24 meters thick at its maximum in the eastern part of the bluffs but thins and wedges out to the west (Easterbrook and others, 1967). Outcrops of the drift are discontinuous and relatively rare. Possession Drift generally lies on the Whidbey Formation and is overlain in most places by Vashon Drift (Easterbrook, 1969).

No deposits in Kitsap County can be positively demonstrated as correlative with Possession Drift and only tentative correlations are made. However, if deposition by Possession ice reached the southern tip of Whidbey Island, only 6.4 kilometers from the Kitsap Peninsula, the glacier very likely also occupied at least part of Kitsap County.

Oxidized sand and gravel found in the southern part of Kitsap County between Olalla and Maplewood may correlate with Possession Drift; this gravel was described initially by Sceva (1957) as the lower member of the Orting gravel, and consists of stratified buff-stained or orange-colored sand and gravel (Figure 26) and some peat and clay (Figure 27). Gravel clasts from deltaic deposits sampled at Maplewood and approximately

Figure 26. Oxidized gravel of Possession (?) Drift near Maplewood.

Figure 27. Peat and clay within gravel of Possession(?) Drift near Maplewood.

Figure 28. Foreset beds in deltaic sand and gravel northwest of Olalla believed to be Possession(?) outwash. Sec. 3, T. 23 N., R. 2 E.

250 meters northwest of Olalla (Figure 28), consist almost entirely of porphyritic andesite, quartz diorite, and some quartz. Molenaar (Garling and others, 1965) mapped the gravel as Salmon Springs Drift and indicated that the sediments were derived from granitic and metamorphic rocks, signifying an origin in the northern Cascades of Washington and British Columbia.

Oxidized gravel, mapped in Kitsap County as Possession Drift or an older deposit (refer to age of Possession, p. 58), is found at University Point and several localities on Bainbridge Island where it consists of pea-to-pebble-size gravel, fine-grained sand, with thin lenses of silt, and peat. The gravel is believed to be of Olympic Mountain origin, based on pebble counts of the gravel and on clast imbrication which indicate a direction of flow from west to east (Figure 29).

Figure 29. Imbrication in gravel derived from the Olympic Mountains (direction of flow west to east), University Point in sec. 19, T. 25N., R. 2 E.

Distribution and Stratigraphic Relationship:

Gravel deposits believed to be Possession Drift are exposed in a bluff near Maplewood (sec. 16, T. 22N., R. 2 E), are overlain by interbedded clay, silt, and fine-grained sand of the Kitsap Formation (Garling and others, 1965). The base of these gravel deposits is not exposed.

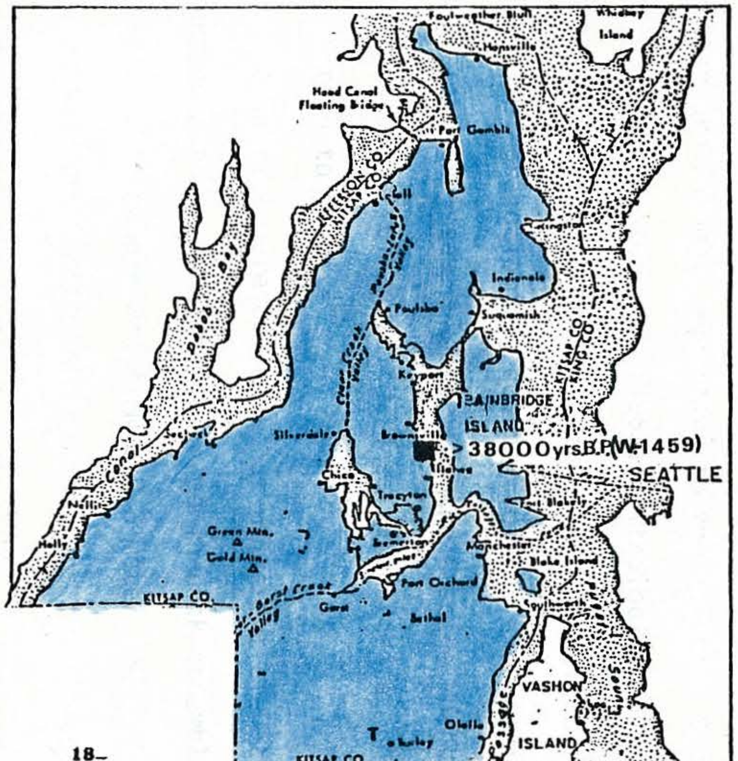
At Olalla oxidized gravel with steeply dipping foreset beds (Figure 28) is believed to represent deltaic deposits. Molenaar (Garling and others, 1965) mapped the gravel as part of the Salmon Springs Drift and believed an unconformity separated the drift from the Esperance sand directly overlying his Salmon Springs strata. I concur with Molenaar's interpretation.

Oxidized gravel and interbedded clay and peat are exposed in a bluff at University Point (sec. 19, T. 25 N., R. 2 E.) (Figure 29; Fugure 30; Plate 2, p. 51). Peat from University Point (Plate 2) was collected by Crandell and Waldron and dated at >38,000 B.P. (W-1459) (Levin and others, 1966) (Table 5, p. 59). Crandell (Levin and others, 1966) believed these lacustrine and fluvial sediments were deposited during the last major interglaciation. The sand and gravel in this unit, consisting of reworked basaltic sandstone, vein quartz, and graywacke with very few granitic rocks, was thought by Crandell (Levin and others, 1966) to have an Olympic Mountain origin. Imbrication of stones in the gravel unit at the base of the University Point exposure shows an orientation of N. 85° E., suggesting that the gravel was deposited by streams whose source was to the west. Part of Crandell's interpretation agrees with mine. That the deposit is nonglacial, seems unlikely in view of the difficulty in explaining how gravel as coarse

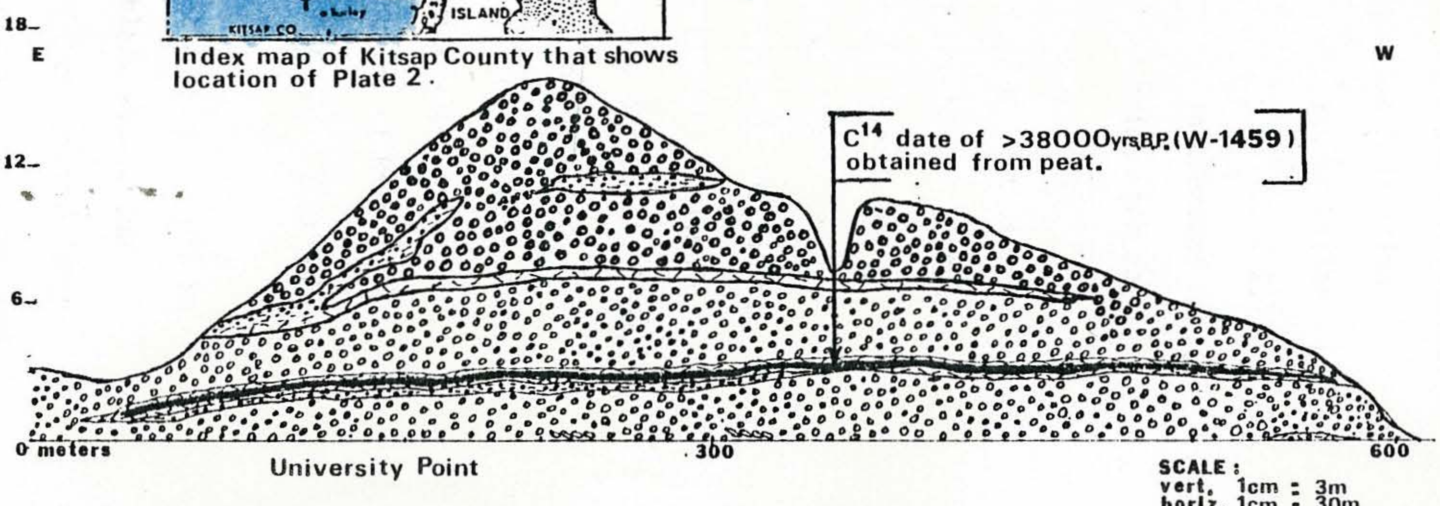
Figure 30. Interbedded clay and peat within thick gravel deposit believed to be Possession Drift at University Point.

PLate 2

Stratigraphic cross section showing C^{14} date of >38000yrs.B.P.(W-1459) obtained from peat interbedded within clay and oxidized gravel of Possession Drift or older at University Point.



Index map of Kitsap County that shows location of Plate 2.



as those found at University Point and on Bainbridge Island could be deposited on a floodplain 18 to 20 kilometers from the Olympic Mountains.

A gravel deposit known to be at least as old as the Possession Drift, based on C^{14} dates, is exposed in a gravel pit east of Miller Road on Bainbridge Island (S.E. ¼, N.E. ¼, sec. 9, T. 25 N., R. 2 E.). The deposit consists of more than 26 meters of gravel, interbedded sand, peat, and clay overlain by Vashon till (Plate 3). A radiocarbon date of >40,000 years B.P. (U.W.-449) from the base of a peat (Plate 3; Figure 31, p. 53; Table 5, p. 54) indicates that this deposit is pre-Fraser and, therefore, is neither an advance Vashon deposit, as it was previously considered by Molenaar (Garling and others, 1965), nor a recessional outwash deposit as it was mapped by Sceva (1957).

Pebble counts were made at two locations (Plate 3) in the pit to determine whether gravels represented a British Columbian or Olympic Mountain provenance. According to the Geologic Survey of Canada, 1959, map 1069A and Easterbrook (1963), lithologies found in the Coast Mountains of British Columbia consist of granitic plutonic rocks, such as granite, granodiorite, quartz diorite, and diorite with associated schists and gneisses. Rocks from the Cascade Mountains of British Columbia consist of andesite, basalt, quartzite, chert, and graywacke, in addition to granite.

The samples were collected at different elevations in the pit to determine whether a change occurred in rock assemblage within the section. Each sample was from a 0.3 meter area. Three hundred forty-five stones were identified by hand lens from each sample location, and rock type percentages determined. Pebbles that could not be identified

PLATE 3

Stratigraphic cross section showing gravel of Olympic Mountain provenance interbedded with sand, silt, and peat in county gravel pit off Miller Road on Bainbridge Island. Location of Plate 3 indicated on page

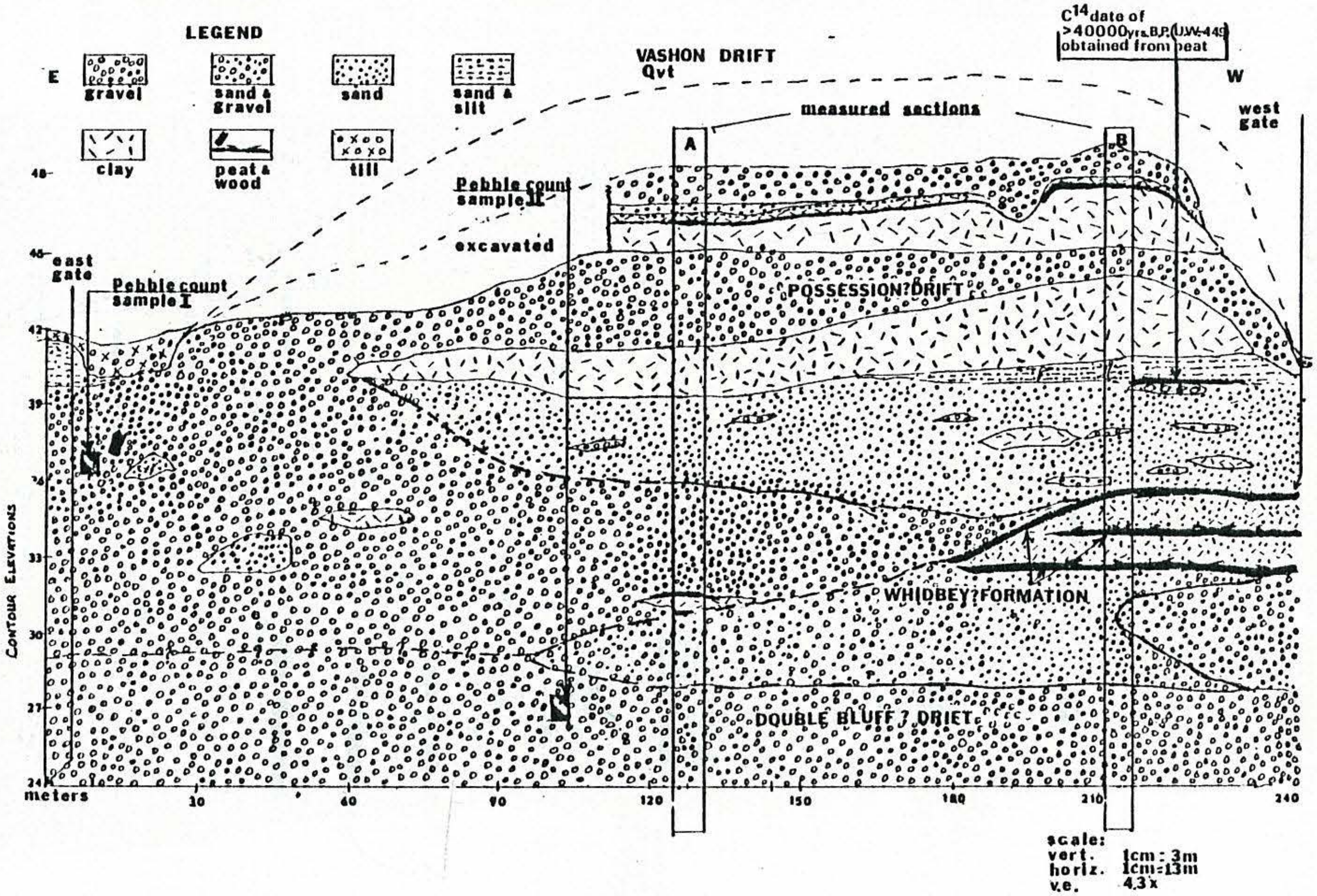
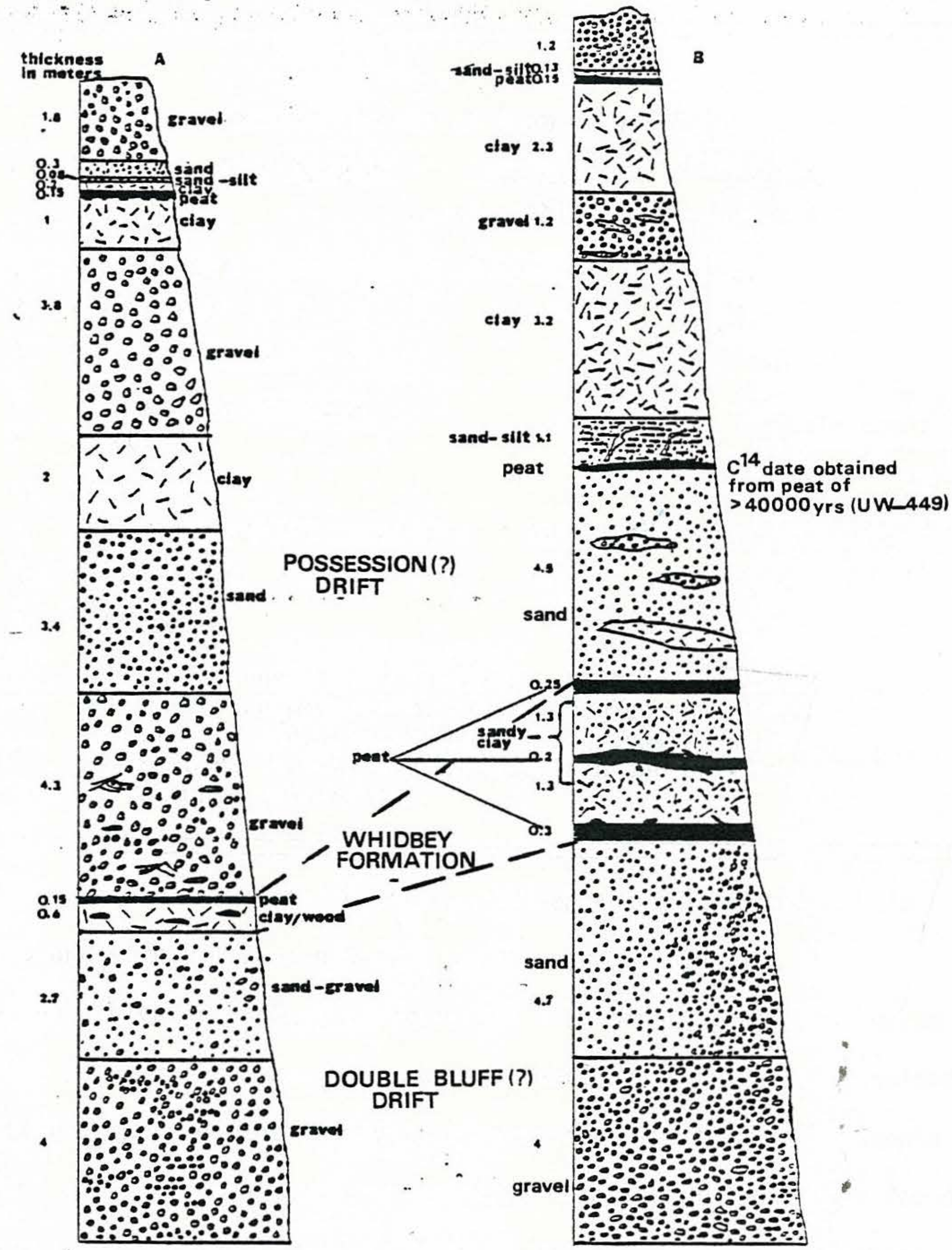


Figure 31

Two measured stratigraphic sections from county gravel pit at Miller Road Bainbridge Island



by hand lens were sent to the Department of Natural Resources, Geology Division, in Olympia, where identification was made by binocular microscope.

Results of the pebble counts are shown in Table 4.

Table 4

PEBBLE COUNTS FOR MILLER ROAD GRAVEL PIT

Lithologies from Sample	Sample I (345 pebbles)	Sample II (345 pebbles)
1. Graywacke*	85%	82.0%
2. Vein quartz	10%	0.4%
3. Quartz diorite		5.0%
4. Porphytitic andesite		3.1%
5. Epidote		0.2%
6. Meta sediment		2.2%
7. Reworked basaltic sandstone	2%	2.0%
8. Unidentified	3%	1.5%
9. Granite		$<$1.0%

*Samples underlined indicate a British Columbia Provenance while remaining lithogies are Olympic Mountain provenance except for graywacke which is found in both Olympic Mountain and British Columbia provenances.

Sample I (Figure 31) contained a high percentage of graywacke, vein quartz, and some reworked basaltic sandstone. Sample II also contained a high percentage of graywacke with minor amounts of quartz diorite, porphyritic andesite, meta sediments, vein quartz, and epidote. Both samples were essentially void of granitic clasts ($<$1%). Sample I contains a rock assemblage which is representative of rock types found in the Olympic Mountains (Tabor, 1975; Kurt Othberg, oral communication, 1978) while Sample II, obtained at the base of the gravel deposit,

Figure 32. Location of Sample I pebble count in gravel of Olympic Mountain provenance at Miller Road gravel pit in sec. 9, T. 25 N., R. 2 E.

contains rock types found in the Olympic Mountains, northern Cascades, and Coast Range. The northern provenance rocks (quartz diorite, porphyritic andesite, and granite) are found in decreasing amounts upward in the section and, most likely represent reworked gravel of a previous glaciation. The gravel also decreases in size upward from pea-to-pebble--size with a corresponding decrease in grain size in the matrix, indicating a decrease in depositional energy. The gravels were probably deposited by meltwater streams issuing forth from alpine glaciers in the Olympics which, at times, extended across Hood Canal and into Kitsap County (Molenaar and Noble, 1970). A glacial, rather than nonglacial origin, for the gravel deposit is proposed both because of difficulties in explaining alpine glaciers advancing from the Olympic Mountains across Hood Canal during an interglaciation and also because the nature of coarse gravel deposits in the lowland on an interglacial floodplain is difficult to explain especially when present day streams do not carry anything as coarse as these deposits. Crandell (1964; 1965) indicates that three major alpine glaciations occurred in the Olympic Mountains in late Pleistocene time and it is believed that the gravel deposits at University Point and Bainbridge Island may correspond with one or more of these.

Other gravel deposits believed by the author to be correlative with those in the measured section at Miller Bay and with the University Point section are found at: (1) Fletcher Bay (sec. 20, T. 25 N., R. 2 E.) (Figure 33); (2) an abandoned gravel pit off of Highway 305 (sec. 4, T. 25 N., R. 2 E.) (Figure 34); and (3) north of Rolling Bay 1.6 kilometers (sec. 2, T. 25 N., R. 2 E.) (Figure 35). Deposits at each of these

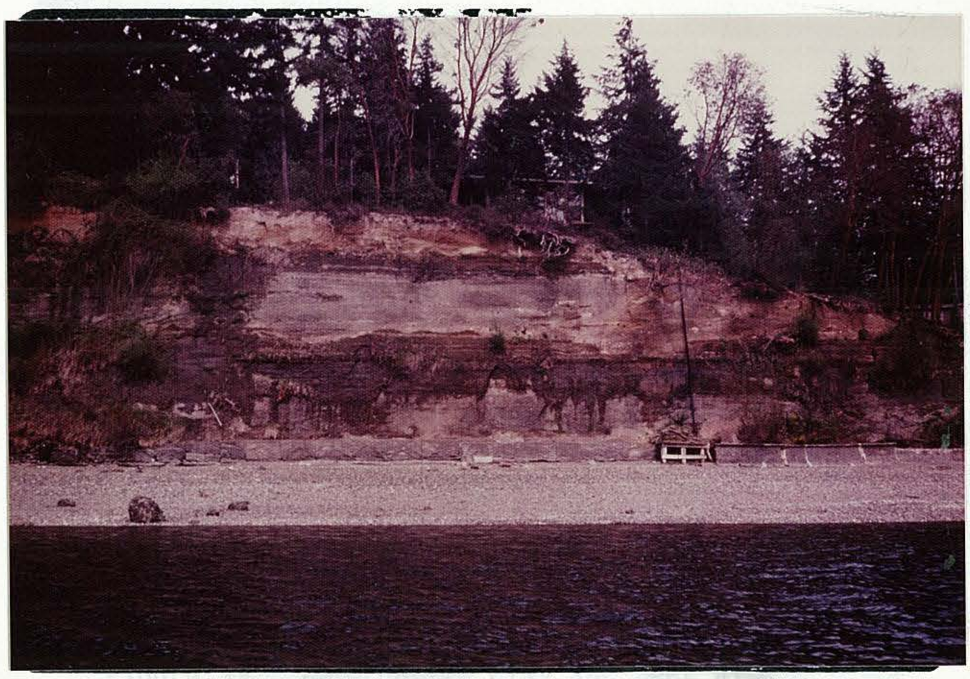


Figure 33. Peat and clay interbedded in gravel believed to be of Olympic Mountain derivation at Fletcher Bay in sec. 20, T. 25 N., R. 2 E.

Figure 34. Slightly oxidized pea-to-pebble-size gravel of Olympic Mountain derivation in gravel pit south of Hidden Cove, Bainbridge Island in sec. 9, T. 25 N., R. 2 E.

Figure 35. Interbedded clay and peat within thick gravel deposit north of Rolling Bay. Sediments thought to be Possession Drift or older, and to correlate with gravel, clay, and peat at University Point in sec. 2, T. 25 N., R. 2 E.

consist of slightly oxidized pea-to-pebble-size gravel (Figure 34) with thin lenses of silt and fine sand. The gravel deposits contain rock types found in the Olympic Mountains, consisting of vein quartz, reworked basaltic sandstone, epidote, graywacke, and less than 1% granitic clasts.

Age and Correlation:

According to Easterbrook (1969), the Possession Drift represents a post-Sangamon glaciation in the Puget Lowland that is correlative with the Salmon Springs Glaciation in the southern Puget Lowland. Hansen and Easterbrook (1974) report that a date of 47,600 $^{+\,3000}_{-\,1000}$ years B.P. was obtained from the older of two peats in the Possession Drift and that a date of 34,900 $^{+\,3000}_{-\,2000}$ years B.P. (I-1880) was obtained from the younger peat.

At the type locality of the Salmon Springs Glaciation, peat interbedded between the upper and lower tills was radiocarbon dated at 50,000 ±400 years B.P. (Crandell and others, 1958). The most recent date obtained from the same unit by Stuiver and others (1978) was 71,500 $^{+\,1700}_{-\,1400}$ years B.P.. The latter date makes the correlation between the lower Salmon Springs Drift and Possession Drift somewhat less likely but does not completely rule such a correlation out. C_{14} dates and dated sample locations from Possession Drift are referred to in Table 5 and Figure 36 on the following page.

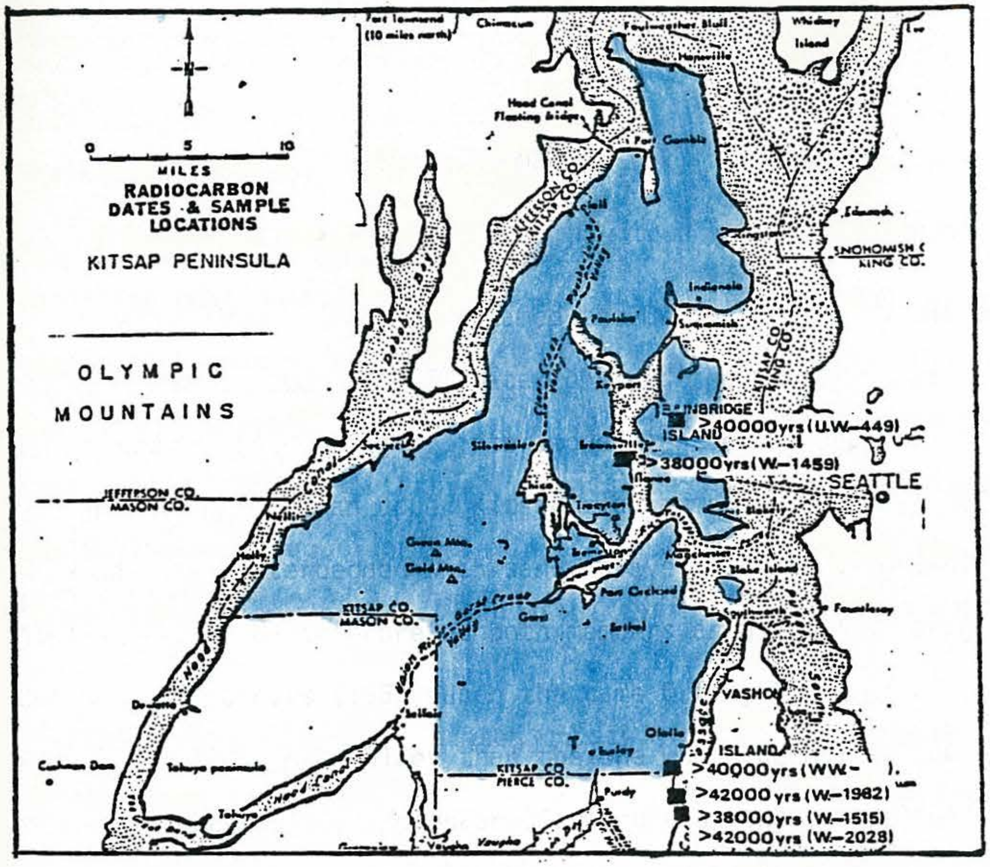


Figure 36. C^{14} dates and sample locations in Possession Drift.

Table 5

C^{14} DATES FROM POSSESSION DRIFT (?) IN KITSAP COUNTY

Date and Sample Number	Location	Source
> 40.000 years B.P. (WW)	Maplewood, Wash. N.E. ¼, S.E. ¼, sec. 9, T. 22 N., R. 2 E. Latitude: 47° 24' 40" N. Longitude: 122° 33' W.	Collected by Mackey Smith (oral communication) from upper peat lying between oxidized gravel units.
> 42,000 years B.P. (W-1982)	Maplewood, Wash. N.W. ¼, S.E. ¼, sec. 16, T. 22 N., R. 2 E. Latitude: 47° 23' 45" N. Longitude: 122° 33' W.	Peat sample previously dated and described by Crandell (Marsters and others, 1969) as overlying oxidized till of Possession Drift.
>38,000 years B.P. (W-1515)	Maplewood, Wash. N.E. ¼, N.E. ¼, sec. 21, T. 22 N., R. 2 E. Latitude: 47° 23' 15" N. Longitude: 122° 33' W.	Sample collected by Crandell from peat overlain by pre-Vashon till. D.R. Crandell (Ives and others, 1967) believes the pre-Vashon till to be equivalent to Hansen and Mackin's midcliff till (Possession Drift) on Whidbey Island.
>42,000 years B.P. (W-2028)	Maplewood, Wash. N.E. ¼, N.E. ¼, sec. 21, T. 22 N., R. 2 E. Latitude: 47° 23' 15" N. Longitude: 122° 33' W.	Peaty silt of Olympia non-glacial interval underlain by pre-Vashon oxidized till (Marsters and others, 1969).
>40,000 years B.P. (U.W.-449)	Miller Road gravel pit, Bainbridge Island, Wash. S.E. ¼, N.E. ¼, sec. 9, T. 25 N., R. 2 E. Latitude: 47° 40' 17" N. Longitude: 122° 32' 47" W.	Discontinuous peat lense in section of silt, sand, and slightly oxidized gravel. Vashon till overlies the gravel
> 38,000 years B.P. (W-1459)	University Point, Wash. S.W. ¼, S.E. ¼, sec. 19, T. 25 N., R. 2 E. Latitude: 47° 38' 20" N. Longitude: 122° 35' 30" W.	Peat and clay interbedded within gravels thought by D.R. Crandell (Levin and others, 1966).

Kitsap Formation (Qk)

Description and Background:

Willis (1898) originally named the Orting gravel in the southeast Puget Lowland. Sceva (1957) later divided the Orting into: (1) a lower member, consisting of interbedded lenticular deposits of sand and gravel, and (2) an upper Kitsap clay member, consisting of laminated clay and silt interbedded with sand, gravel, lignite, volcanic ash, and glacial till. He interpreted both members as glacial in origin. Crandell and others (1958) used the name Orting for a glaciation in the Puyallup Valley, much older than the one which deposited the gravel on the Kitsap Peninsula. Molenaar (Garling and others, 1965) believed the Kitsap clay member to be nonglacial in origin and the lower gravel to be glacial; therefore, he described them as separate formations.

The type locality of the Kitsap Formation is a sea cliff on the west side of Colvos Passage in the southern part of Kitsap County between Maplewood and Olalla (sec. 9, T. 22 N., R. 2 E.). Molenaar (Garling and others, 1965) described the Kitsap Formation there as lying conformably above, and interfingering with the underlying oxidized gravel which he assigned to the Salmon Springs Glaciation. According to him the Kitsap Formation consists of finely laminated silt and clay, in contrast to the thicker, more massive, and contorted clays of the undifferentiated pre-Salmon Springs deposits exposed elsewhere in Kitsap County. Molenaar (Garling and others, 1965) included a silt stratum 0.3 to 1.2 meters thick, near the top of a thick sequence of oxidized gravel, as part of the Kitsap Formation and believed it represented the transition from a glacial environment to a nonglacial one without an erosional interval.

The Kitsap Problem:

A number of major problems with Molenaar's definition of the Kitsap Formation pose questions as to whether or not the Kitsap Formation is a viable rock unit.

The main problems with the Kitsap Formation as defined by Molenaar are: (1) Molenaar's interpretation of the depositional interval includes any well stratified, finely laminated silt or clay; thus the Whidbey Formation, Possession Drift, and sediments of the Olympia nonglacial interval may be grouped together within the Kitsap Formation; (2) Molenaar may have misinterpreted the type of contact between the oxidized gravel of the Salmon Springs Drift and the overlying fine-grained sediments of the Kitsap Formation; and (3) discrepancies in radiocarbon dates within the Kitsap Formation and differences between these and C^{14} dates in the Olympia nonglacial sediments elsewhere in the Puget Lowland.

Molenaar (Garling and others, 1965) believed the Kitsap Formation was deposited during the Olympia nonglacial interval, yet by his description of the formation as any well stratified, finely laminated clay, he has included three separate depositional intervals. This causes a problem in mapping stratigraphic relationships involving fine-grained sediments because by definition these sediments were all deposited during the Olympia nonglacial interval, when in fact they may be older than the Olympia.

The thin silt and peat lens at the type locality, which Molenaar interpreted as a transition between the glacial deposits and the overlying floodplain deposits, is localized and pinches out in all directions within a short distance. The oxidized gravel above and below the fine-grained sediment does not change in particle size, matrix, rock type, or in any other distinguishing characteistics. At the contact between the oxidized gravel and overlying thick nonglacial sediments of the Kitsap Formation, an unconformity appears to be responsible for an abrupt change from coarse gravel to silt and clay. Molenaar believed the contact to be gradational, without an erosional interval; thus, he chose an arbitrary boundary for the Kitsap Formation at the base of the thin lens of silt and peat. A more practical contact is between the top of the gravel and the overlying fine-grained sediments. The contact Molenaar has used is not representative of the contact elsewhere in Kitsap County, and by including the upper gravel as part of the Kitsap Formation, he has deviated from the fine-grained nonglacial description originally used in defining the Formation.

Radiocarbon dates from sediments of the Olympia nonglacial interval elsewhere in the Puget Lowland are within limits of C^{14} dating, whereas the Kitsap Formation sediments are not (>42,000). Easterbrook (1968) noted that there are discrepancies in dates from the same peat beds in the Kitsap Formation, casting doubt on the reliability of dates in the sequence and making stratigraphic position of the peat beds unclear. Radiocarbon dates obtained from the Kitsap Formation at various localities in the Kitsap Peninsula prior to 1962 ranged from 20,000 to 35,000 years B.P.. These early dates provided much of the basis for assigning the Kitsap Formation to the Olympia Interglaciation since dates for the Interglaciation ranged from 20,000 to 40,000 years B.P.. Resampling at many of the previously dated localities has revealed new dates beyond the limits of conventional C^{14} dating. As an example, peat near the type locality of the Kitsap Formation at Maplewood was initially dated at 32,700 $\pm$ 1000 (U.W.-25) from a sample collected in 1961 by G. Kimmel (Dorn and others, 1962, p. 5); resampling and dating of the same peat by Crandell and others (Marsters and others, 1969) gave a date of >42,000 years B.P. (W-1982).

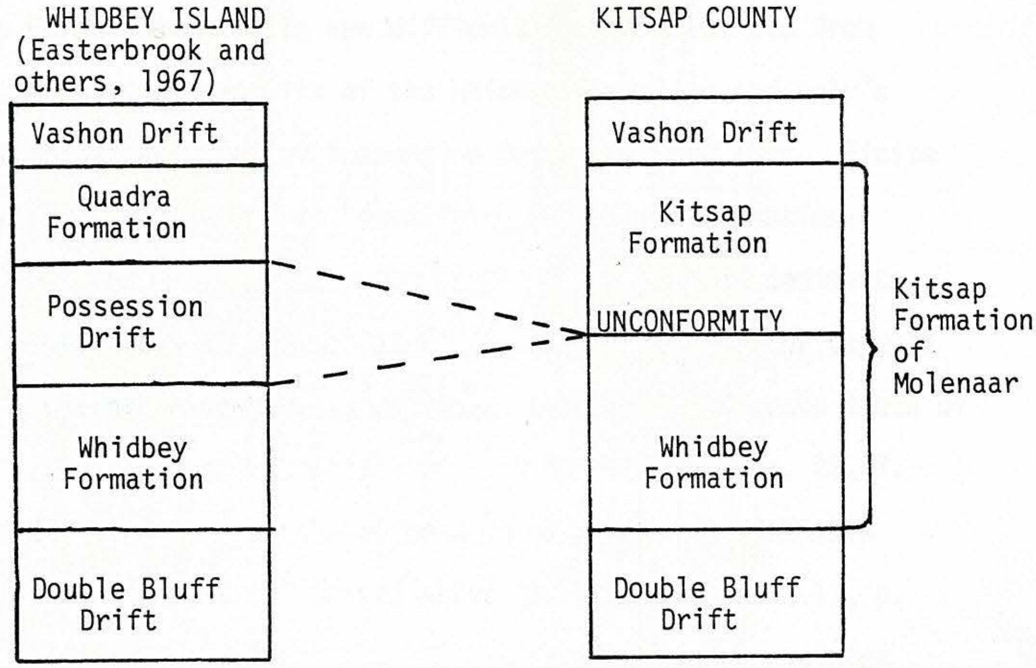
In addition to discrepancies in radiocarbon dates, new evidence suggests that the time interval represented by the Olympia nonglacial interval is shorter than previously believed. Instead of extending from 20,000 to more than 40,000 years ago, new radiocarbon dates and palynological evidence suggest that the older age limit lies between 28,000 and 35,000 years B.P. (Hansen & Easterbrook, 1974). The vegetational history recorded in peat bogs on the Olympic Peninsula supports the concept that the Olympia is younger than 35,000 years (Heusser, 1972). Therefore, many deposits with C^{14} dates beyond the limits of conventional laboratory techniques that have been assigned to the Kitsap Formation may belong to either the Whidbey Formation or Possession Drift.

Last, even if Possession ice extended no farther than the southern end of Whidbey Island, its influence would have had a significant effect on the climate in Kitsap County. This change of environment from a non-nonglacial climate to glacial climate would serve as a transition period between sediments deposited before and during the Possession Glaciation with pollen analysis within the deposits indicating this change. In many instances, the Kitsap may unconformably overlie the Whidbey with most evidence of Possession removed by erosion (Figure 37). The latter situation has occurred in Kitsap County and Molenaar has mapped both Whidbey and Olympia sediments as part of the Kitsap Formation.

Proposed Changes of the Kitsap Formation:

In view of the problems involved with Molenaar's Kitsap Formation, the author proposes modification of the Formation. Because one of the major problems appears to be the transition of glacial to nonglacial

Figure 37



sediment, the interbedded peat and silt between the two oxidized gravels at Molenaar's type locality of the Kitsap Formation should be considered Possession Drift, rather than part of the Kitsap Formation (refer to the Kitsap Problem, p. 61). Because the time interval for the Olympia non-glacial interval, to which Molenaar (Garling & others, 1965) assigned the Kitsap Formation, is between 15000 to 35,000 years B.P. it is proposed that fine-grained sediments whose age lies within this time interval (as determined by pollen analysis or C^{14} dating) be assigned to the Kitsap Formation. Fine grained nonglacial sediment for which stratigraphic relationship or age (based on C^{14} or pollen analysis) cannot be determined shall be assigned to a Whidbey-Kitsap Undifferentiated unit.

Age and Stratigraphic Correlation:

Kitsap Formation deposits are difficult to differentiate from underlying, nonglacial deposits of the Whidbey Formation and only a limited number of exposures of Possession Drift separate them. Finite radiocarbon dates are useful in identifying the Kitsap Formation.

Recent C^{14} dates obtained by the author in nonglacial sediments in Kitsap County are within upper and lower age limits set for Olympia nonglacial sediments elsewhere in the Puget Lowland. Sediments south of Point-No-Point, in the extreme north part of the county (sec. 22, T. 28 N., R. 2 E.) contained pieces of wood in compact clay with thin discontinuous sand lenses 2.5 meters above the beach (Plate 5.11, p. 117; Figure 38C; Figure 39, p. 67). Medium-grained sand containing silt clasts overlies the compact clay and is overlain by 1 to 1.2 meters of laminated clay. Vashon till overlies the laminated clay at this location, but an increasing thickness of Esperance sand separates them towards the south. Two samples of wood were collected on separate occasions and dated at two different laboratories to check validity. One sample was dated by A. Fairhall, University of Washington, at 15,450 ± 250 years B.P. (U.W.-448) (Figure 38C; Figure 39; Table 6, p. 77). The second sample was dated by Isotopes, Inc. at 15,350 ± 210 years B.P. (I-10,374) Table 6, p. 77).

Fine-grained nonglacial sediment overlying the dated clay and sand lens increases in thickness southward. At approximately 400 and 670 meters south of the dated section the dated clay is overlain by 23 and 28 meters respectifully of interbedded sand and massive to laminated clay, with several meters of Esperance sand and Vashon till overlying (Figure 38A & B; Figure 40, p. 67; Figure 41, p. 68).

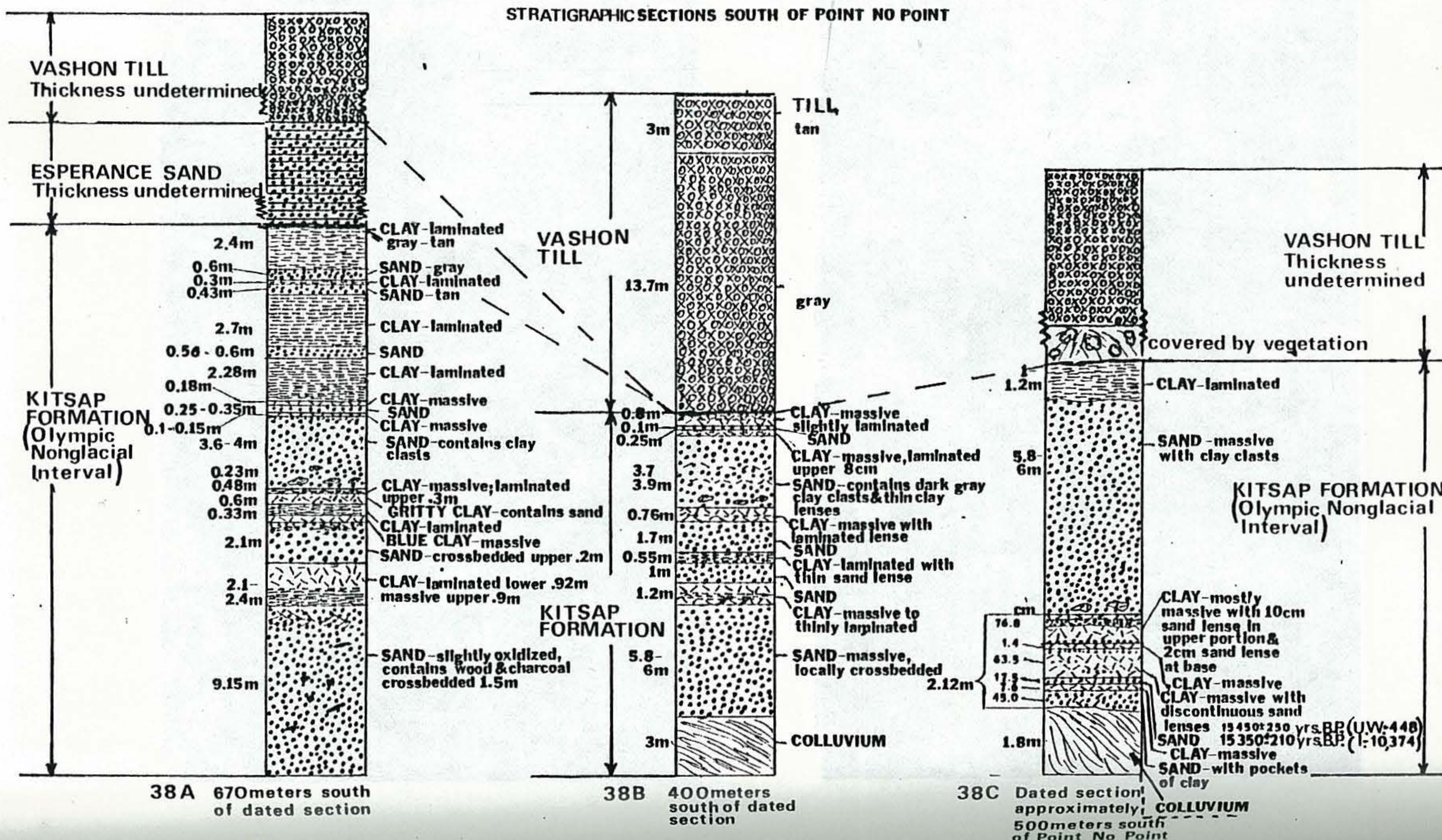


Figure 38 Three measured stratigraphic sections within the Kitsap Formation [illegible]

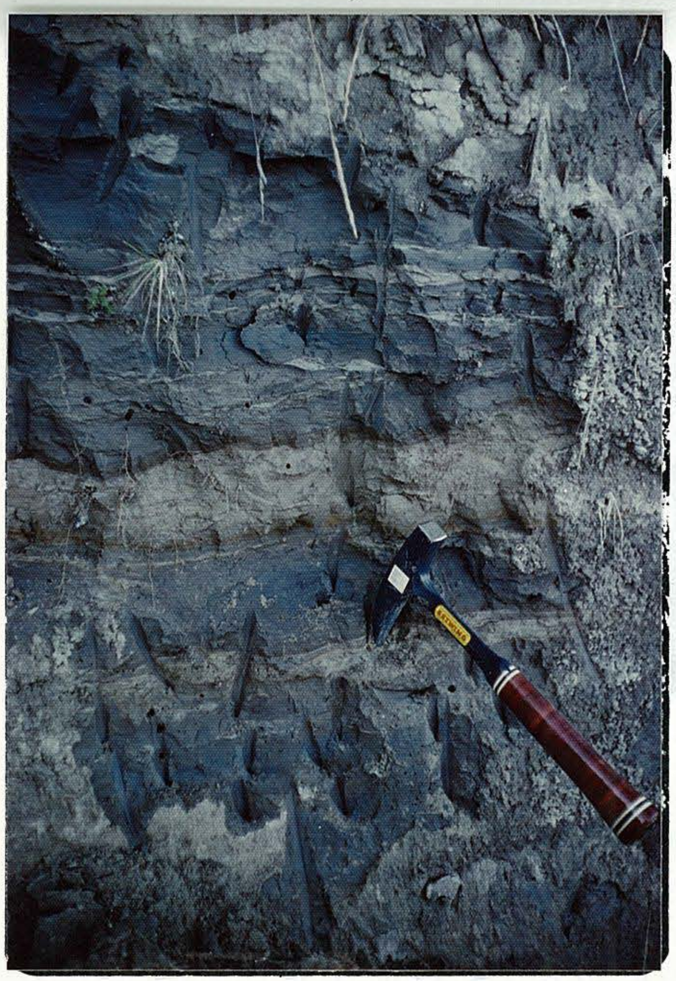


Figure 39. Interbedded blue-gray clay and fine gray sand several meters above beach near Point-No-Point in sec. 22, T. 28 N., R. 2 E. Dated at 15,450 ± 250 years B.P. (U.W.-448) and 15,350 ± 210 years (I-10,374).

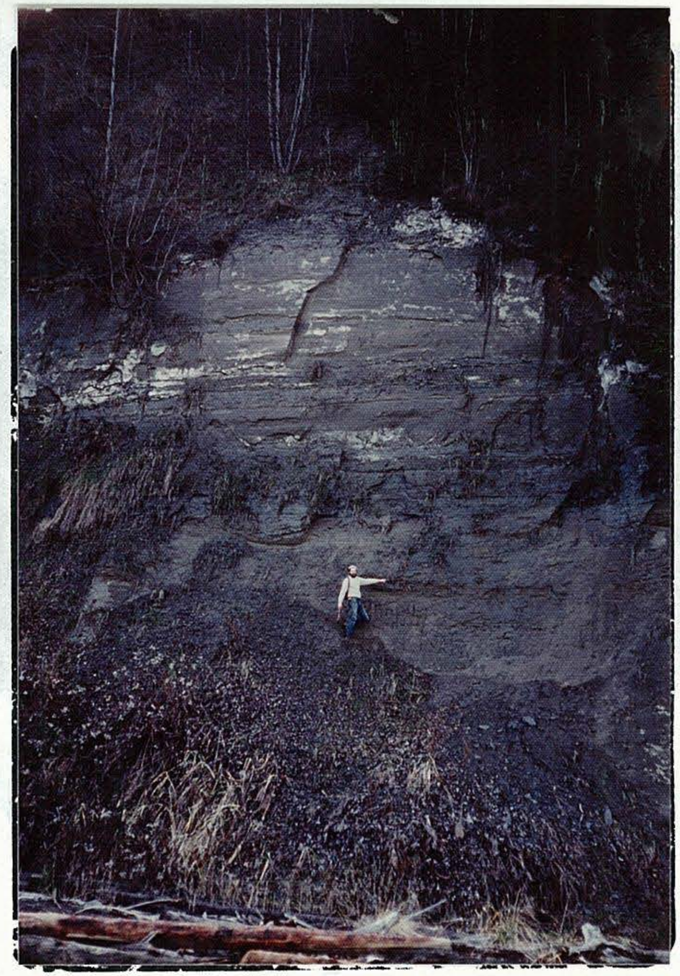


Figure 40. Bedded sand and clay of Olympia nonglacial interval south of Point-No-Point in sec. 22 and 27, T. 28 N., R. 2 E.

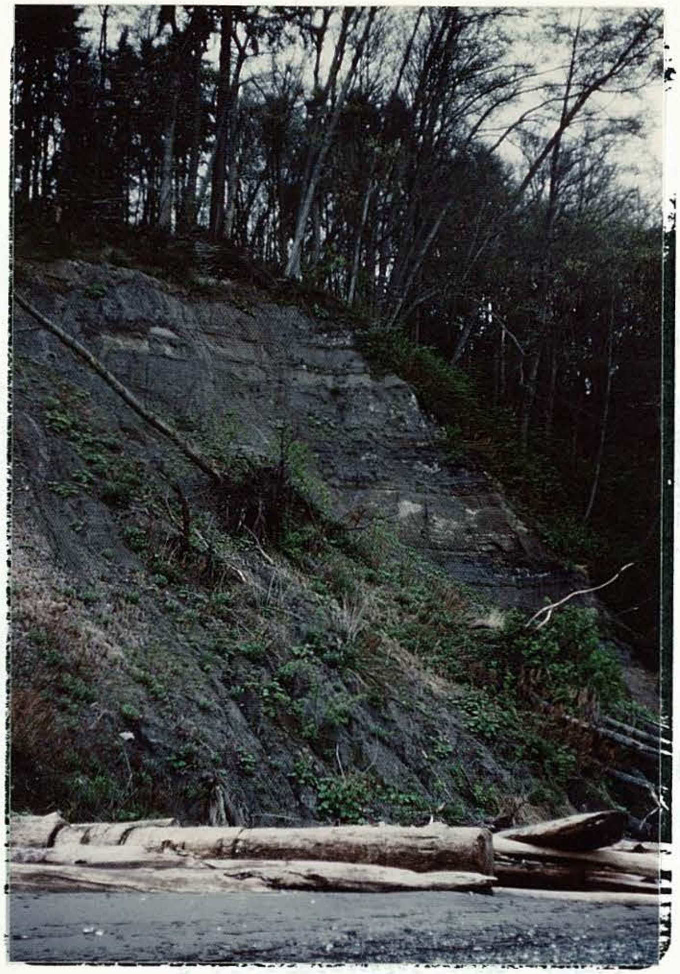


Figure 41. Interbedded sand and laminated clay of the Olympia nonglacial interval south to Point-No-Point in sec. 27, T. 28 N., R. 2 E.

The C^{14} dates from the nonglacial floodplain sediments of 15,450 ± 250 years B.P. (U.W.-448) and 15,350 ± 210 years B.P. (I-10,374) correspond to dates from pre-Vashon nonglacial sediments approximately 35 kilometers south in Seattle. There, a date of 15,000 ± 400 years B.P. (W-1227) is thought by Mullineaux and others (1965) to indicate that Vashon ice did not advance into the area until after 15,000 years ago.

Just south of the mouth of Barker Creek on the east side of Dyes Inlet, a large piece of wood from compact, dark gray clay (Plate 4, p.69; Figure 42, p. 71) gave a C^{14} date of 16,510 ± 320 years B.P. (U.W.-445) Table 6, p.77). Massive gray clay at the base is overlain by oxidized gravel consisting of pea-to-pebble-size gravel that varies

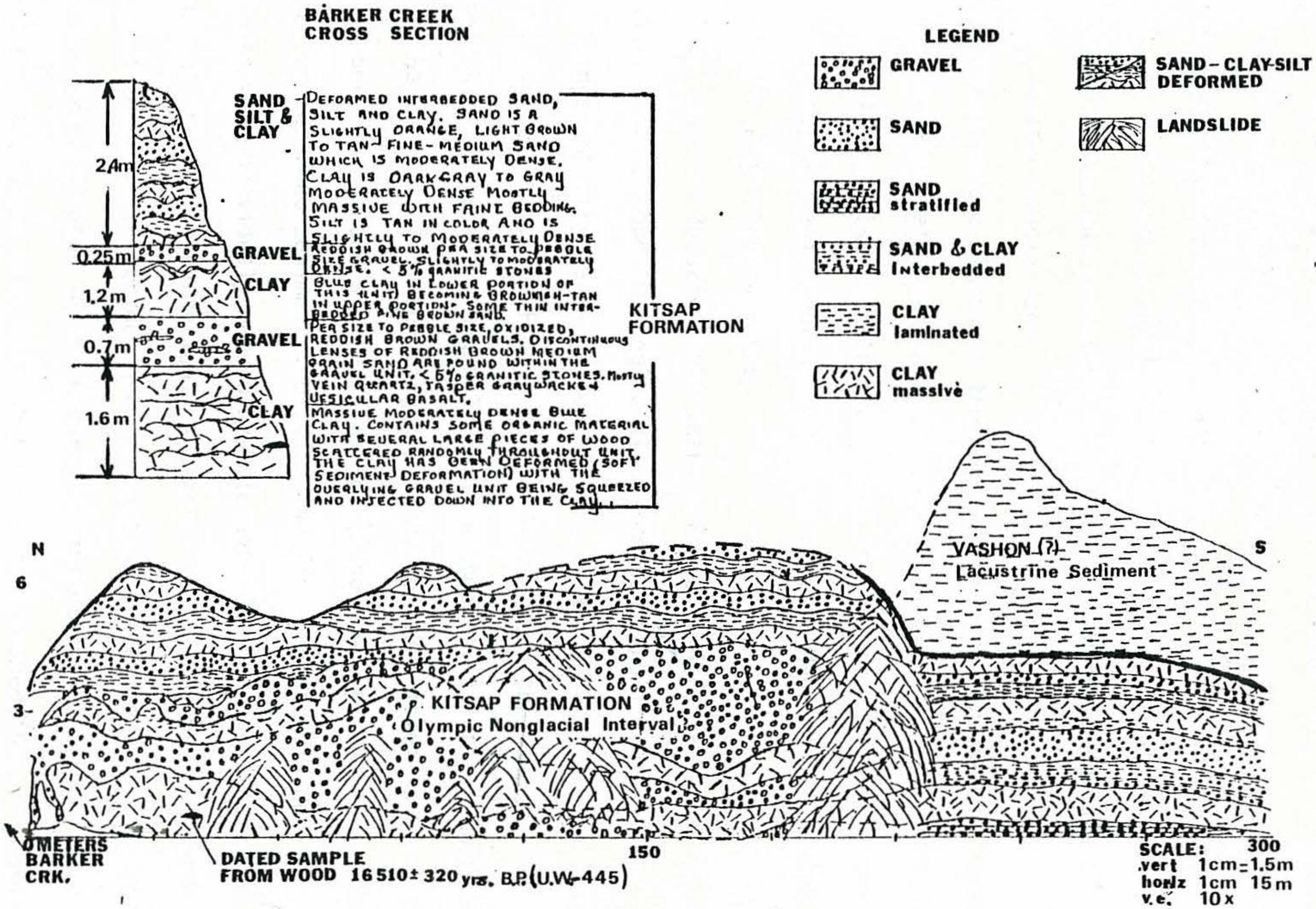


PLATE 4

Stratigraphic cross section showing interbedded fine-grained sediments and oxidized gravel from the mouth of Barker Creek south 300 meters. Location of Plate 4 indicated on page.

in thickness from 0.76 to 3 meters. Some of the oxidized gravel appears to have been squeezed downward into the underlying clay, perhaps by the overriding Vashon ice. A finely bedded, light gray clay, which overlies interbedded sand, silt, and clay in the south part of the section, is in marked contrast to the rest of the sediments exposed in the section and may represent a proglacial lacustrine deposit of the early Fraser Glaciation.

Oxidized pebble clasts in the measured section consist of graywacke, vesicular basalt, vein quartz, and granite. If the C^{14} date of 16,510 years B.P. in the clay beneath the gravel is correct, the gravel may represent alpine glacial outwash from the Olympic Mountains immediately prior to the Puget lobe advance.

A C^{14} date of 36,325 ± 2680 years B.P. (U.W.-446) Table 6, p. 77) was obtained from wood in nonglacial sediments approximately 400 meters north of the Kingston ferry landing (sec. 25, T. 27 N., R. 2 E) (Plate 5.1, p. 105; Figure 43, p. 71; Figure 44, p. 72). The dated sample was obtained 0.6 meters above beach level in a compact, faintly bedded, blue clay. The deposits from the Kingston ferry to 1.2 kilometers north of it have been folded and slightly faulted (Figure 45, p. 73) (refer to section on deformed sediments, p.74). The fine-grained floodplain sediments were previously mapped by Molenaar (Garling and others, 1965) as part of the Kitsap Formation. Blue-gray clay, thought to be proglacial because of its gradational contact with the overlying Esperance sand, becomes laminated in the upper 30 centimeters and changes to a medium-grained, light gray sand that contains crossbedding and several thin silt lenses. The sand becomes coarser upward in the section, grading into gravel in the upper 0.3 meters where it is overlain by Vashon till. Description and location for all recent C^{14} dates obtained

Figure 42. Interbedded, clay, silt, sand and gravel. Date of 16,510 ± 320 years B.P. (U.W. 445) obtained in lower gray clay 0.5 meters above beach south of Barker Creek in sec. 28, T. 25 N., R. 2 E.

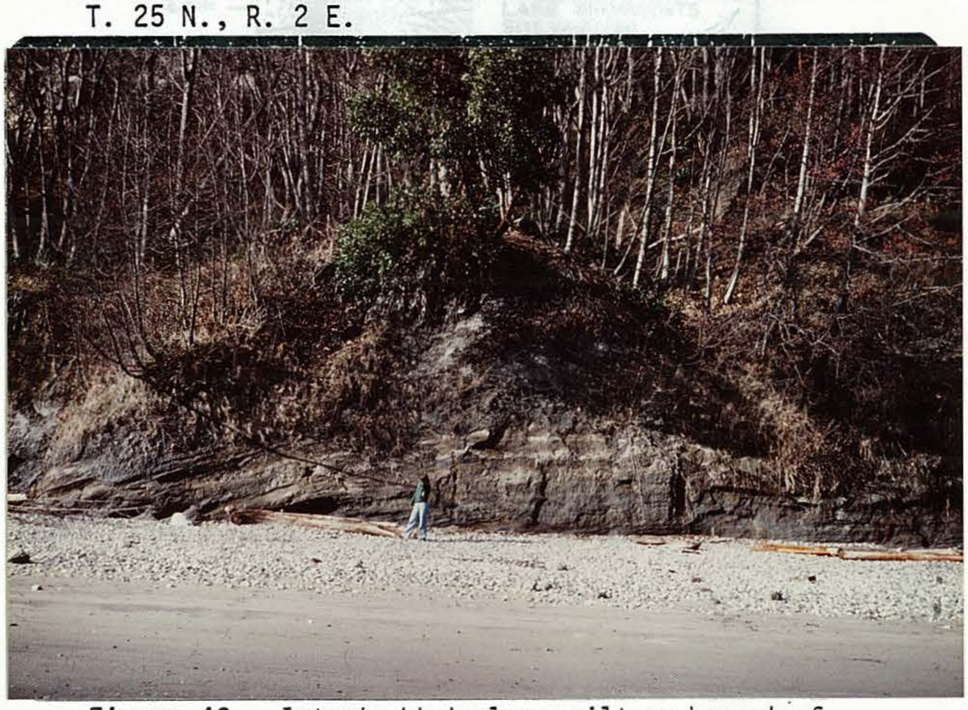


Figure 43. Interbedded clay, silt and sand of Olympia nonglacial interval in small anticline north of Kingston ferry landing in sec. 25, T. 27 N., R. 2 E.

Figure 44 Composite stratigraphic section showing C^{14} dated nonglacial sediments of the Kitsap Formation overlain by Vashon Drift approximately 400 meters north of the Kingston Ferry Landing.

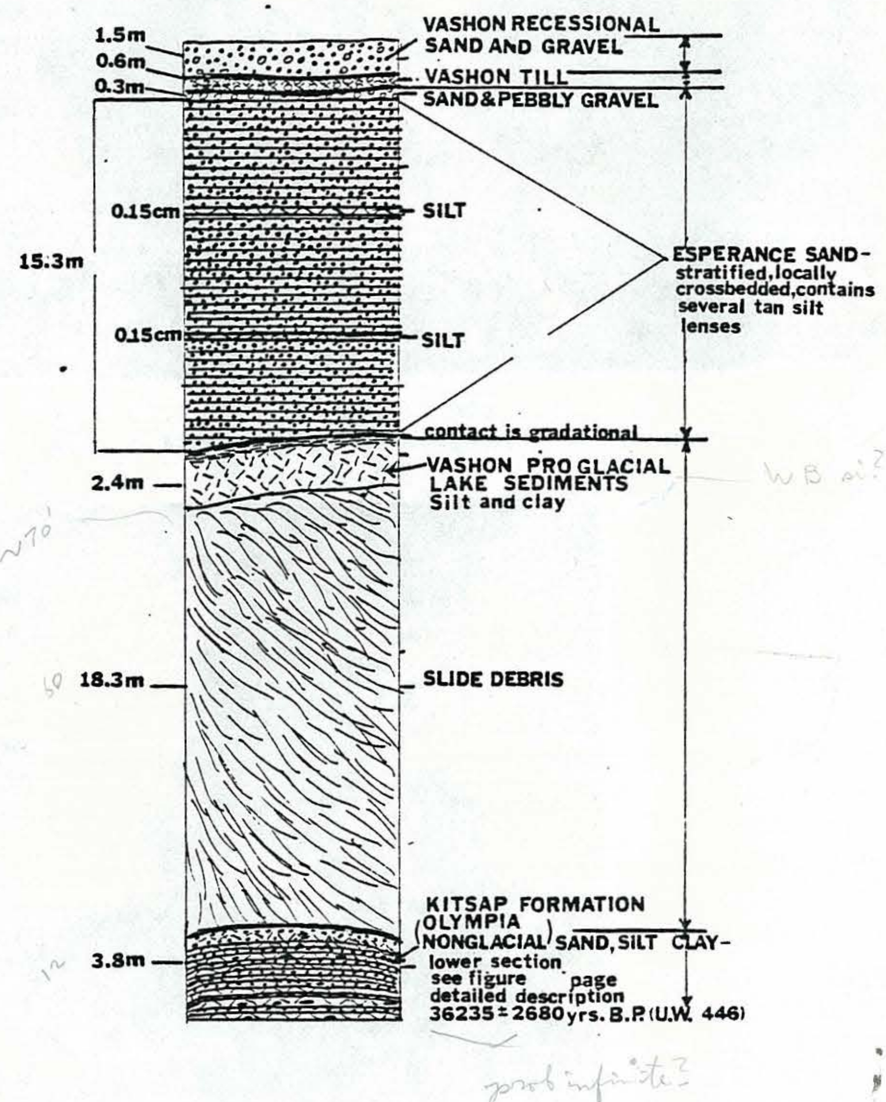


Figure 45. Faulted and folded clay with clastic dikes in sand, north of Kingston ferry landing in sec. 25, T. 27 N., R. 2 E

Figure 46. Injected fine sand and silt into overlying Esperance sand, south of Sheltered Bay in sec. 29, T. 28 N., R. 2 E.

within the Kitsap Formation in Kitsap County are indicated at the end of the section on the Kitsap Formation in Table 6, p. 77 and Figure 49 p. 77

Deformation:

Nonglacial deposits from the Kingston Ferry terminal to 1.2 kilometers north have been deformed into small anticlinal and synclinal folds. The sediments have been slightly faulted with maximum displacement of 40 centimeters (Figure 45, p.73). Clastic dikes are observed in the fine-grained sediment.

Interbedded, dense, fine-grained sand and silt with some clay of the Olympia nonglacial interval or older, exposed at the base of sea cliffs at Skunk Bay (Plate 6.3, p. 121), Coon Bay Plate 6.10, p.128; Plate 6.11, p. 129), and north of Little Boston (Plate 6.12, p. 130) is deformed in many places. The fine-grained sediments have been injected upward into overlying Esperance sand, forming large diapir folds (Figure 46, p. 73). Some of the folds rise as much as 4.6 meters into the overlying sand and have been compressed (Figure 47; Figure 48). Bretz (1913) described sediment deformation at several locations in the central Puget Lowland, including the north side of Useless Bay on Whidbey Island and along Hood Canal, a few miles south of Foulweather Bluff. In the lower part of stratified clay, peat, sand, and gravel that make up most of the exposure at Useless Bay, Bretz (1913) described clean, gray sand mixed with irregular masses of clay 3 meters in diameter and 9 to 15 meters apart. The clay masses are usually elongated vertically and have irregular arms projecting vertically and horizontally into the sand (Figure 48). Horizontally bedded sand and clay lie above the deformed strata. Bretz (1913) recognized similar structures south of Foulweather Bluff along Hood Canal.

Figure 47. Tightly folded diapir folds, consisting of fine to medium sand and silt with dips of 66° northwest to 70° southeast, south of Sheltered Bay in sec. 19, T. 28 N., R. 2 E.

Figure 48. Deformed fine sand, silt, and clay that has been squeezed up into overlying sand at Skunk Bay in sec. 18, T. 28 N., R. 2 E.

Several possible causes for the deformation according to Bretz (1913) are: (1) lateral compression, (2) vertical intrusion, (3) plastic clay below quicksand which gave the clay mobility, or (4) ice shove. More than one of the above causes was responsible for the deformation in Kitsap County. In some cases two or three factors may have combined to produce the deformed sediments. The tightly folded sediment near sheltered Bay (Figure 47, p.75) and Skunk Bay (Figure 48, p. 75) appears to be the result of both ice shove and lateral compression whereas the elongated arms of fine-grained sediment injected upward into overlying Esperance sand south of Sheltered Bay (Figure 46, p. 73) appears to be the result of vertical intrusion and quicksand conditions.

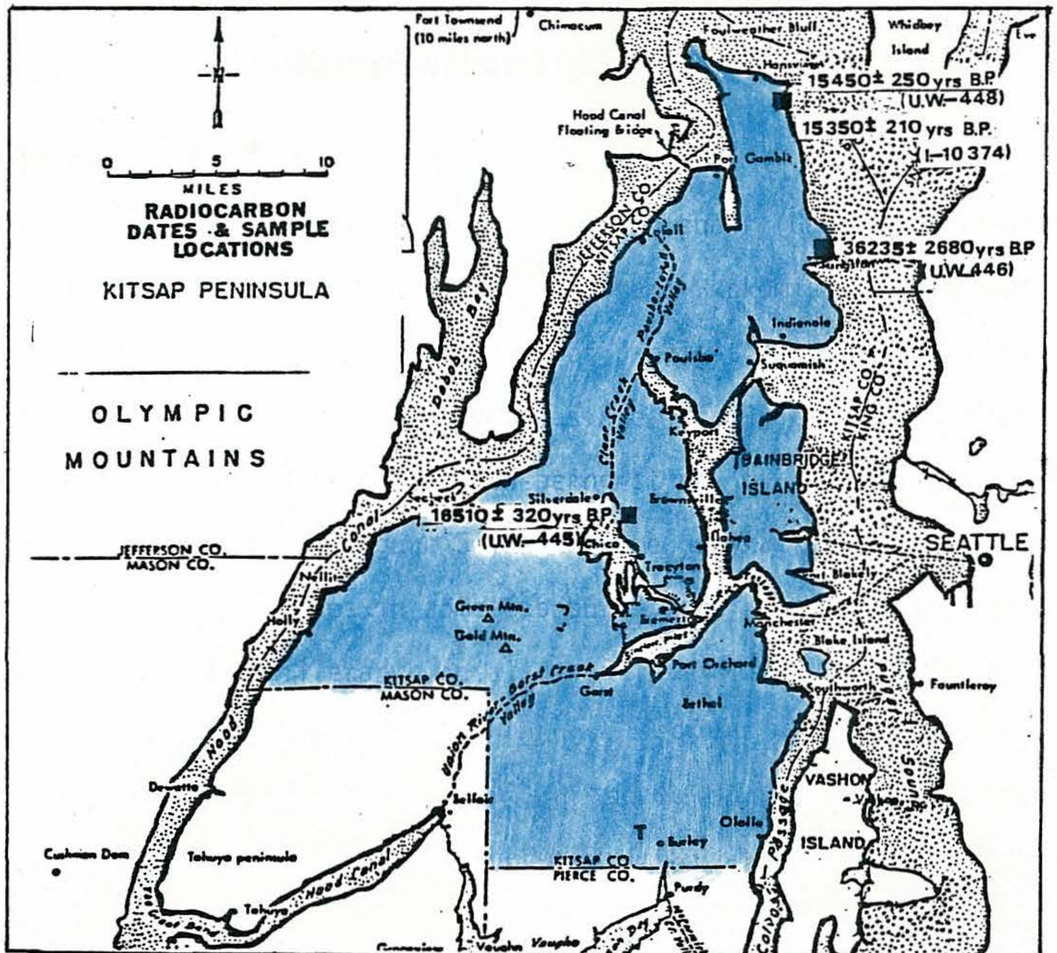


Figure 49. C^{14} dates sand sample localities in the Kitsap Formation.

Table 6

C^{14} DATES FROM KITSAP FORMATION
IN KITSAP COUNTY

Date and Sample Number	Location	Source
15,450 + 250 years B.P. (U.W.-448) 15,350 + 210 years B.P. (I-10,374)	Point-No-Point, Wash. N.W. ¼, N.E. ¼, sec. 22, T. 28 N., R. 2 E. Latitude: 47° 54' 09" N. Longitude: 122° 31' 36" W.	Wood within clay and discontinuous sand lenses. Dated unit is overlain by interbedded sand, clay, and Vashon till.
36,235 + 2680 years B.P. (U.W.-446)	Kingston, Wash. S.E. ¼, N.W. ¼, S.W. ¼, sec. 25, T. 27 N., R. 2 E. Latitude: 47° 48' 05" N. Longitude: 122° 29" 22" W.	Wood within massive blue clay and interbedded sand 3.8 m thick.
16,510 + 320 years B.P. (U.W.-445)	Barker Creek, east side of Dyes Inlet, Wash. Sec. 21 and 28, T. 25 N., R. 1 E. Latitude: 47° 38' 11" N. Longitude: 122° 40' 19" W.	Wood within compact, dark gray clay 0.45 m above beach in interbedded, oxidized gravel, silt, sand, and clay.

Skokomish Gravel (Qs)

Description:

An unnamed gravel previously mapped by Molenaar (Garling and others, 1965) in Kitsap County was later given the name Skokomish by Molenaar and Noble (1970). This gravel consists of pebble-to-cobble-size stones, oxidized orange to dark red. The pebbles are locally cemented and so weathered that some disintegrate upon being struck by a rock hammer. The clasts are mainly basalt (Figure 50) with some graywacke, slate, and sandstone. Granite pebbles in some exposures were considered to represent reworking of Cordilleran glacial deposits (Molenaar and Noble, 1970). In most exposures in Kitsap County, bedding is poor. These gravel deposits were thought to represent deposition by alluvial fans extending beyond the foothills of the Olympic Mountains.

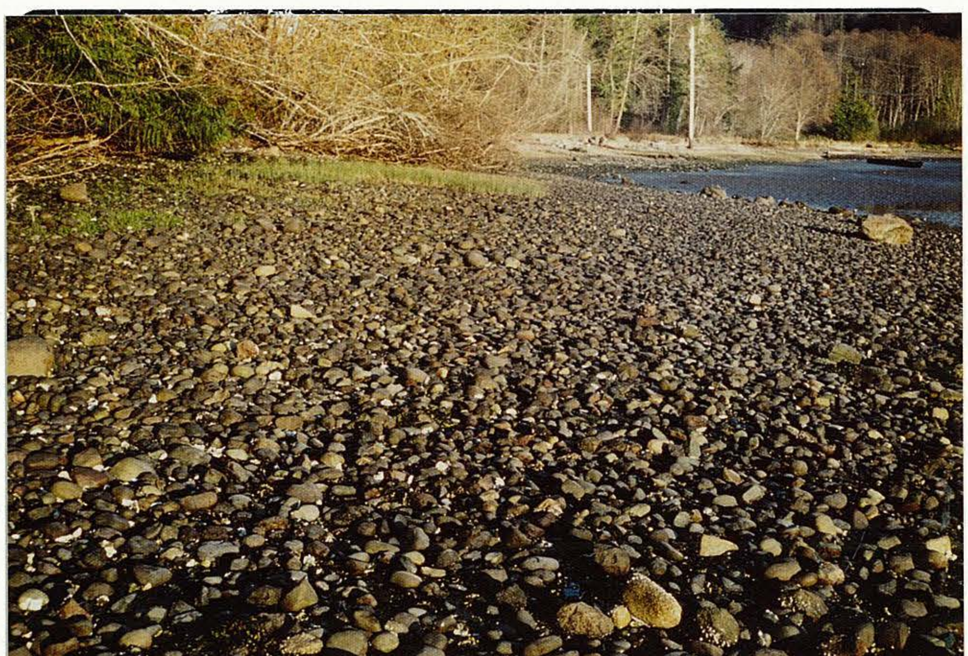


Figure 50. Basalt cobbles of Olympic Mountain derivation found on beach near Holly.

Discontinuous lenses of clay, silt, sand, and peat less than 1.2 meters thick are associated with the gravel. The clay and silt is usually tan to yellowish brown while the sand is reddish brown.

Distribution:

Skokomish gravel is found mainly in sea cliff exposures adjacent to Hood Canal, south of Holly. Deposits are also found north of this site in scattered exposures along the shoreline south of Bangor.

The gravel exposed between Holly and Bangor is generally less than 30 meters thick and is overlain by Vashon Drift. South of Holly, gravel is exposed in the lower portion of steep bluffs which are 150 to 180 meters high. The author was not able to observe the gravel above 30 meters due to the steepness of the slopes and to the vegetation cover. Therefore, the exact thickness of the gravel is uncertain, but it may reach 60 meters thick, as mapped by Molenaar and Nobel (1970) in Mason County.

Age and Stratigraphic Correlation:

The Skokomish gravel is thought by Molenaar (Garling and others, 1965) and Noble (Molenaar and Noble, 1970) to interfinger with sediments of the Kitsap Formation and, therefore, to be nonglacial. They believe, furthermore, that pebbles of northern provenance in the base of the gravel represent reworking of the underlying Salmon Springs Drift because northern provenance gravel is found in decreasing amounts up section. Molenaar and Noble (1970) interpreted the Skokomish gravel as derived from the Olympic Mountains.

Gravel at Bainbridge Island and at University Point may be correlative with the gravel along Hood Canal. The presence at these sites of vein quartz, reworked basaltic sandstone, and epidote, as well as absence of substantial amounts of northern provenance stones other than graywacke (which is present in both northern and Olympic Mountain provenances) provides some support for an Olympic Mountain derivation. The main problem in correlating the gravel units at Bainbridge Island and at University Point with the gravel unit along Hood Canal is the stratigraphic relationship of the gravel unit to the Kitsap Formation.

Molenaar (Garling and others, 1965) interprets interbeds of reddish to yellowish silt and clay with some peat strata in the Skokomish gravel along Hood Canal in Kitsap County as indicating the gravel's nonglacial characteristic and correlation with the more widespread Kitsap Formation.

This interpretation is questionable for the following reasons: (1) the exact nature of the contact between the Kitsap Formation and Skokomish gravel is unclear in Molenaar and Noble's report (1970); (2) discrepancies in Molenaar's useage of the Kitsap Formation and; (3) the gravel on Bainbridge Island and at University Point is, in most cases, fairly oxidized but only slightly weathered--yet it was beyond conventional radiocarbon dating, whereas gravel and related sediments mapped as Skokomish along Hood Canal are described as slightly to considerably weathered by Molenaar (Garling and others, 1965) which indicates the gravel may be older than the Kitsap Formation as defined in this paper. No C^{14} dates have been obtained from the lower Skokomish-Kitsap sediments along Hood Canal, and no conclusive evidence exists that the gravel was deposited during the Olympia nonglacial interval. However, because positive evidence for correlating the gravel at Hood Canal with gravel deposits at University Point and Bainbridge Island is lacking, the gravel at Hood Canal is mapped as part of the Skokomish gravel until more evidence is available.

Vashon Drift

Vashon Drift consists of proglacial lacustrine sediments, advance sand and gravel of the Esperance sand, till, and recessional outwash deposited during the Vashon Stade of the Fraser Glaciation.

Vashon Drift was deposited sometime between 15,000 and 13,500 years B.P.. A C^{14} date of 15,350 years B.P. (I-10,374) obtained from wood collected by the author from nonglacial sediments directly below Vashon till at Point-No-Point, and a similar date of 15,000 years B.P. (W-1227) (Mullineaux and others, 1965) obtained near Seattle from nonglacial sediments beneath Vashon till indicate that the ice had not arrived in the central and southern Puget Lowland prior to 15,000 years B.P.. A C^{14} date from sediments in Lake Washington in Seattle indicate the ice retreated north of Seattle by 13,650 years B.P. (L-346A) (Rigg and Gould, 1957). These dates bracket the time during which Vashon ice that deposited the Vashon Drift was present in the southern Puget Lowland: thus ice was present in the Seattle area for less than 1500 years.

A more detailed description of each of the Vashon Drift deposits is discussed on the proceeding pages.

Vashon Lacustrine Deposits (Qvl)

Description:

Vashon lacustrine sediments are ice marginal. Extensive silt and clay were deposited when advancing ice from the north extended across the Strait of Juan de Fuca and blocked northward-draining streams in the Puget Lowland, when ice blocked local drainage, and when lakes formed between lobes of melting ice during deglaciation. The silt and clay range in color from gray to blue with some tan colored silt, and vary in thickness from 4 to 10 meters; bedding is laminated. Differentiating between Vashon clay and the underlying Kitsap or Whidbey Formation clay is often difficult.

Distribution and Stratigraphic Relationships:

Proglacial lacustrine deposits in Kitsap County are correlative with the Lawton Clay Formation (Mullineaux and others, 1965) at the type locality at Fort Lawton in Seattle (Figure 51). Mullineaux defined the Lawton Formation as glacial lacustrine clay and silt deposited in the early stage of the Vashon glacial advance. Correlation with the Lawton in Kitsap County is based on the stratigraphic position and gradational nature of the contact with the overlying Esperance sand. One example north of the Kingston ferry landing (sec. 25, T. 27 N., R. 2 E.) where 2.4 meters of finely bedded lake sediments overlie non-glacial floodplain sediments of the Kitsap Formation and underlie a thick sequence of Esperance sand (Plate 5.1, p. 105). Laminated blue-gray silt and clay grades upward into fine gray sand of the Esperance. These deposits outcrop continuously north almost to Eglon (Plates 5.1 through 5.6 p. 105-110). The clay was deposited on an irregular erosional surface.

Figure 51. Type section of the Lawton Formation in Seattle. Interbedded silt, sand, and clay of the Olympia nonglacial interval is overlain by Lawton clay and Esperance sand. Sec. 16, T. 25 N., R. 3 E.

Similar fine-grained lake sediments are observed along the steep bluff between Brownsville and Keyport where gray massive clay grades upward into fine tan sand and silt and is overlain by Esperance sand. Because of extensive slides in the area, the lower contact of the lake sediments is not exposed.

Finely bedded lenses of silt and clay between dense gray sand occur below stratified Esperance sand near Miller Bay. This deposit was previously mapped by Molenaar (Garling and others, 1965) as Vashon recessional sand.

Exposures of Vashon lacustrine deposits or nonglacial sediments are also found on the east side of Big Valley.

Esperance Sand (Qve)

Description:

Esperance sand was named by Newcomb (1952) in western Snohomish County. He recognized two major units within the Esperance and stated that "the earlier phase of the sand member appears to be a coarser continuation of the Admiralty clay, whereas the later outwash phase is undoubtedly the advance outwash of the Vashon glacier." Mullineaux and others (1965) redefined Newcomb's earlier definition of Esperance sand and restricted it to the "later outwash phase" of Newcomb. Mullineaux's Esperance sand at Fort Lawton consists of fine to medium grained sand that contains some thin silt beds. Lenticular beds of coarse sand and granule-to-pebble gravel are common, and in some areas increase upward in abundance, thickness, and coarseness. The sediments display several types of stratification. Most commonly the lower part of the sand is massive or horizontally bedded, suggesting early deposition occurred in quiet water. Current bedding and cut and fill stratification become more abundant toward the top, indicating fluvial deposition. Foreset bedding indicates that direction of transport of sediment was southward or southeastward.

The term Esperance sand in this paper is restricted to the outwash phase of Newcomb (1952) as redefined by Mullineaux and others (1965).

Esperance sand in Kitsap County grades from fine-to medium-grained sand in the lower part of the unit to coarse-grained sand with lenses of gravel in the upper part. The lower sand unit is often massive or finely bedded and contains thin, discontinuous lenses of dense tan silt, usually less than 15 centimeters thick. The sand is light gray to tan and is mostly loose and friable. The upper part of the Esperance sand consists of coarser advance outwash deposits, including stratified, ice-contact and deltaic deposits.

The stratified ice contact deposits consist of discontinuous lenses of gravel, sand, silt, and clay. Material within a particular lens is moderately sorted but because of the close proximity of the ice, grain size varies widely between lenses.

Deltaic deposits are better sorted than ice contact deposits and consist mostly of sand and gravel overlain by glacial till. Foreset beds often dip steeply.

Distribution and Stratigraphic Relationships:

The Esperance sand is widely distributed in the central and northern parts of the county.

Good exposures of Esperance sand occur from the Kingston ferry landing north to approximately one kilometer south of Point-No-Point (Plates 5.1 through 5.12, p. 105 through 118). Well stratified, medium-grained sand, reaches a maximum thickness of 55 meters. At one location north of Apple Cove Point (sec. 24, T. 27 N., R. 2 E.), 18 meters of massive, fine-grained tan to light brown sand is overlain by 22 meters of brown to gray medium-grained, stratified sand. This sand underlies Vashon till and overlies proglacial lake sediments. The sand grades upward from fine to coarse, suggesting that the ice was approaching during deposition.

Exposures of Esperance sand occur in the east valley wall along Big Valley, north of Poulsbo (sec. 2, T. 26 N., R. 1 E.); south of Port Orchard along Highway 12 (sec. 6, T. 24 N., R. 1 E.); at Misery Point

Figure 52. Esperance sand, stratified and interbedded with thin lenses of gravel at Misery Point in sec. 17, T. 25 N., R. 1 W.

(sec. 17, T. 25 N., R. 1 W.) (Figure 52), and south of Fletcher Bay in the upper part of the bluff (sec. 29, T. 25 N., R. 2 E.).

Extensive Vashon advance sand and gravel in the southwest part of the county along Hood canal appear to be ice contact sediments deposited over nonglacial sand, silt, and clay as a lobe of ice advanced along the present site of Hood Canal. In places, recessional gravel overlies the advance deposits. These differ from the lower advance deposits only in degree of compaction and oxidation. Flow till occurs in numerous exposures.

Ice contact deposits in the bluff directly behind the Olalla Store at Olalla (sec. 3, T. 22 N., R. 2 E.) consist of slightly deformed sand and gravel. The gravel is compact; in some cases, it is slightly cemented and underlain by gravel mapped as Salmon Springs by Molenaar (Garling and others, 1965). Advance sand and gravel between Olalla and Southworth are overlain by Vashon till and underlain by non-glacial sediments just north of Wilson Creek (sec. 11, T. 23 N., R. 2 E.).

In the gravel pit just east of the South Port Orchard Airport (sec. 34, T. 23 N., R. 1 E.) 16 meters of Vashon advance outwash sand and gravel is overlain by 3 meters of Vashon till. Similar sand and gravel at the North Kitsap Gravel Pit (sec. 19, T. 25 N., R. 1 E.) is 18 to 22 meters thick. Twelve to 15 meters of Vashon advance sand & gravel at Point Jefferson (sec. 13, T. 26 N., R. 2 E.) is overlain by Vashon till (Figure 53).

Foreset beds in Vashon advance deltaic gravels at Werner Road in Bremerton (sec. 21, T. 24 N., R. 1 E.) dip to the northeast 13 to 24 degrees. The gravel is underlain by sand and overlain by Vashon till.

Figure 53. Vashon advance sand and gravel overlain by Vashon lodgement till at Point Jefferson in sec. 13, T. 26 N., R. 2 E.

Vashon Till (Qvt)

Description:

Vashon till was deposited by the last major Pleistocene glacier in the Puget Lowland, which occurred during the Vashon Stade of the Fraser Glaciation (Armstrong and others, 1965). Most of the upland areas in Kitsap County are mantled by till, consisting of poorly sorted clay, silt, sand, and gravel deposited during advance and recession of Vashon ice. Lodgement till at the base of the ice has been compacted and stands in nearly vertical bluffs along the shoreline. The till is gray in most places, but the color varies with the amount of oxidation. Sandy till frequently has a slightly brownish color, whereas till with abundant clay has a bluish tinge. Thickness of the till ranges from very thin lenses up to 20 meters. The tops of most sea cliff exposures are mantled by till with south-facing sea cliffs having thicker deposits of till than sea cliffs facing north. Difference in thickness is related to the nature of till deposition beneath the ice and the direction of ice movement from north to south. Little or no weathering has occurred in the till.

Ablation till, deposited as ice melted, is less compact than lodgement till. Many of the finer silt and clay particles have been washed away by meltwater. The thickness of ablation till is from 0.5 to 3 meters and it is generally underlain by lodgement till. Most clasts are rounded to subangular, indicating a fluvial environment prior to incorporation in the till. Northern provenance rock types present in the till consist of granite, diorite, quartz diorite, schist, and gneiss, with graywacke and porphyritic andesite also present. Some local Tertiary volcanic rocks and Blakely Formation clasts are found in till deposits in the south half of the county.

Distribution:

Vashon till is widespread throughout Kitsap County. In the southwest part of the county between Holly and Lake Tahuya, lodgement till is overlain by ablation till, consisting of approximately 0.6 to 1.2 meters of loose, unsorted, coarse gravel. Small depressions, underlain by lodgement till, mark the surface of the upland in this part of the county and are the site of numerous swamps and peat bogs. In the southeast part of the county between Long Lake and Olalla, a thin discontinuous sheet of till is present. Green and Gold Mountain in central Kitsap County are mantled by Vashon till. The till ranges in thickness from 0.5 to 3 meters and contains a high content of basalt and gabbro derived from the local bedrock that make up these hills.

Stratigraphic Relationships:

The base of Vashon till generally rests unconformably upon the underlying Pleistocene deposits, and in some cases, upon Tertiary bedrock. The unconformity varies from a marked angular unconformity to a less distinguishable disconformity. In places where Vashon till rests upon older till, a large thickness of till is observed, as in the sea cliff north of the Eglon public boat launch (Plates 5.8 and 5.9, p. 114 and 115), where more than 40 meters of till is exposed. Vashon till is generally overlain by Vashon recessional deposits or recent alluvium.

Vashon Recessional Outwash

Recessional Outwash Sand (Qvrs) and Gravel (Qvrg)
Ice Contact Deposits (Qvri)
Deltaic Deposits (Qvrd)

Description and Distribution:

Recessional outwash from the Vashon glacier varies greatly in depositional environment, thickness, and extent. Recessional outwash may be deposited by meltwater streams in large outwash channels, as deltaic deposits, and as ice contact deposits. The outwash is generally poorly sorted, consisting of a wide range of northern provenance rock types with some local rock types. Individual particles range in shape from mostly well-rounded to subrounded. The recessional outwash overlies till, which is the major criterion for distinguishing between recessional and advance outwash. Because Vashon till is not always present, difficulty often arises in making the distinction.

Recessional outwash is deposited on valley floors from meltwater streams flowing away from the ice front. These deposits consist of fine- to coarse-grained sand with some gravel and range in thickness from 0.5 to 3 meters. In some instances, recent alluvium has been deposited over the recessional outwash.

Typical recessional outwash sediments deposited in meltwater channels are found on the floor of Big Valley, north of Poulsbo, in Clear Creek Valley, northwest of Silverdale, and in the Olalla Valley, south of Long Lake (Figure 54). A good exposure of foreset beds dipping southeast are found in recessional sand deposits along the northeast side of Olalla Valley (Figure 55, p. 92) near Olalla.

Ice marginal streams flowing along lobes of Vashon ice and adjacent

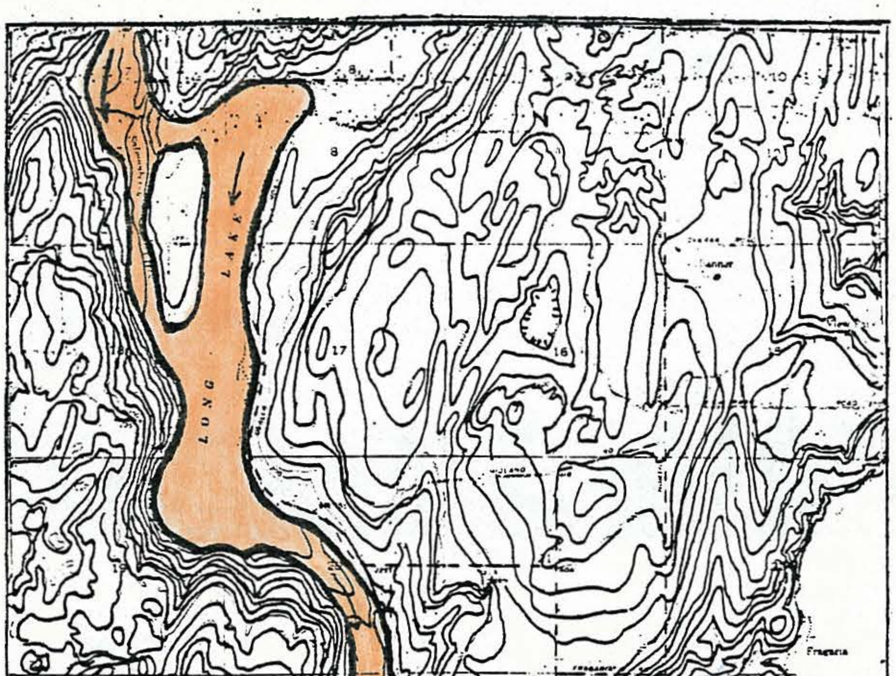


Figure 54
Vashon meltwater drainage in Olalla Valley was south to southeasterly. Pre-Vashon deltaic deposits adjacent to Olalla Bay show foreset beds which dip to the northeast.

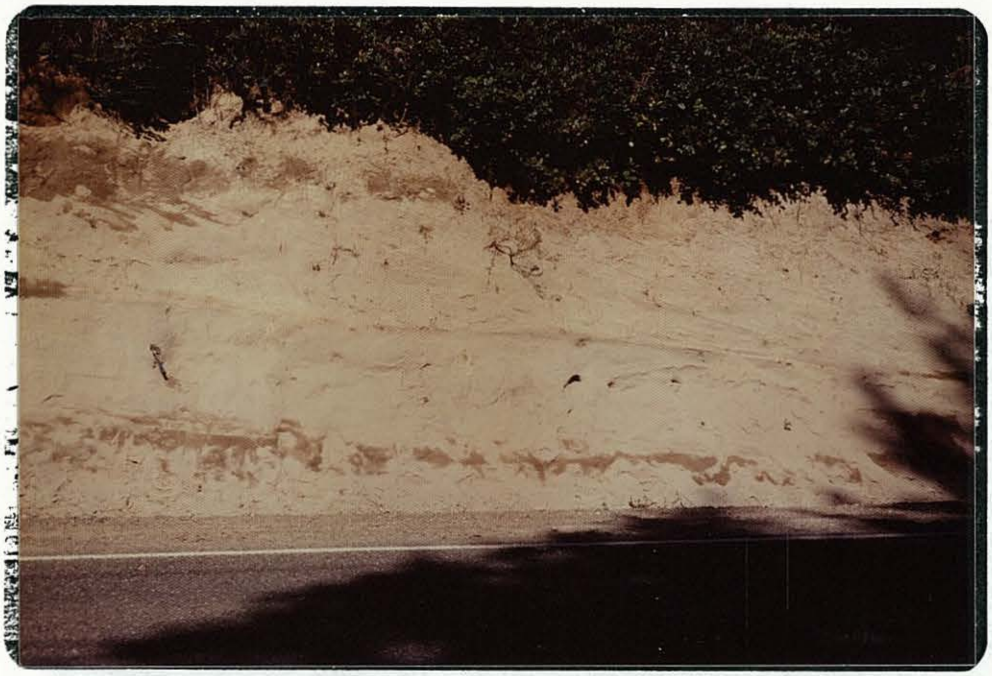


Figure 55. Foreset beds in Vashon sand indicate drainage from northwest to southeast during past maximum ice stand of Vashon Stade in Olalla Valley in sec. 4, T. 22 N., R. 2 E.

landmasses during deglaciation in Kitsap County were responsible for deposition of recessional ice contact sediments. The ice contact deposits form kame terraces higher on valley walls. Some flat-topped ridges next to valleys and steep bluffs next to marine embayments are mantled with recessional deposits; they consist of moderately sorted, discontinuous lenses of silt, sand, and gravel. Flow till is also incorporated within the deposits. Ice contact sediments show deformation as a result of sag, slump, or collapse (Figure 56; Figure 57); they form pitted outwash terraces with kames and kettles. Typical recessional ice contact deposits occur in the Gorst Creek Valley, where variable deposits of silt, fine-grained sand, and peat are found in the bottom of the valley with coarser sand and gravel lining the valley walls. Sceva (1957, p. 25) and Molenaar (Garling and others,

Figure 56. Highly deformed ice contact sand and gravel resulting from collapse and slump, in gravel pit west of Horseshoe Lake in sec. 9, T. 22 N., R. 1 E.

Figure 57. Collapse feature in ice contact deposit of sand and gravel approximately 0.8 kilometers west of Dyes Inlet in sec. 30, T. 25 N., R. 1 E.

1965, p. 36) described the depositional environment of the sand in Gorst Creek as outwash accumulated in quiet water burying many large ice blocks. Melting of the ice blocks resulted in formation of kettle topography and in deformation of the strata. Ice marginal streams deposited sand and gravel along the north valley wall (sec. 3, T. 23 N., R. 1 W.) Figure 58). To the west in Mason County, deposits on the floor of Gorst Valley consist of very fine sand and silt formed in a shallow lake during the late stages of deglaciation.

Kame and kettle topography formed during the Vashon recession is also found along Blackjack and Burley Creek Valleys and in the vicinity of the Bethel-Burley Road intersection with Highway 16. The kame terrace deposits consisting of poorly-to-well stratified sand and gravel. On both sides of the Burley Creek Valley (sec. 25 and 36, T. 23 N., R. 1 E.) (Figure 59; Figure 60, p. 96) they contain a high percentage of gravel.

Figure 58. Ice contact sand and gravel adjacent to north valley wall in Gorst Creek Valley in sec. 3, T. 23 N., R. 1 W.

Figure 59. Ice contact stratified sand and gravel on east side of Bethel-Burley Valley in a kame terrace in sec. 25 and 26, T. 23 N., R. 1 E.

West of Horseshoe Lake (sec. 9, T. 22 N., R. 1 E.), ice contact deposits show a high degree of deformation (Figure 56, p. 93). Some of the sand and gravel beds dip to the south, whereas other beds in the pit are folded, with collapse and slump structures and debris flows. The ice apparently stagnated just to the north of this site and melt-water streams transported large loads of sediment, burying blocks of ice.

Ice contact deposits also occur south of Newberry Hill Road (sec. 29 and 30, T. 25 N., R. 1 E.) and in the east valley wall just east of Poulsbo. Silt, sand, gravel, and flow till, were deposited by ice marginal streams during deglaciation at Newberry Hill. Collapse and slump structures can be seen within the deposit (Figure 57, p. 93). At Poulsbo pebble-to cobble-size gravel is overlain by a thin deposit of silt.

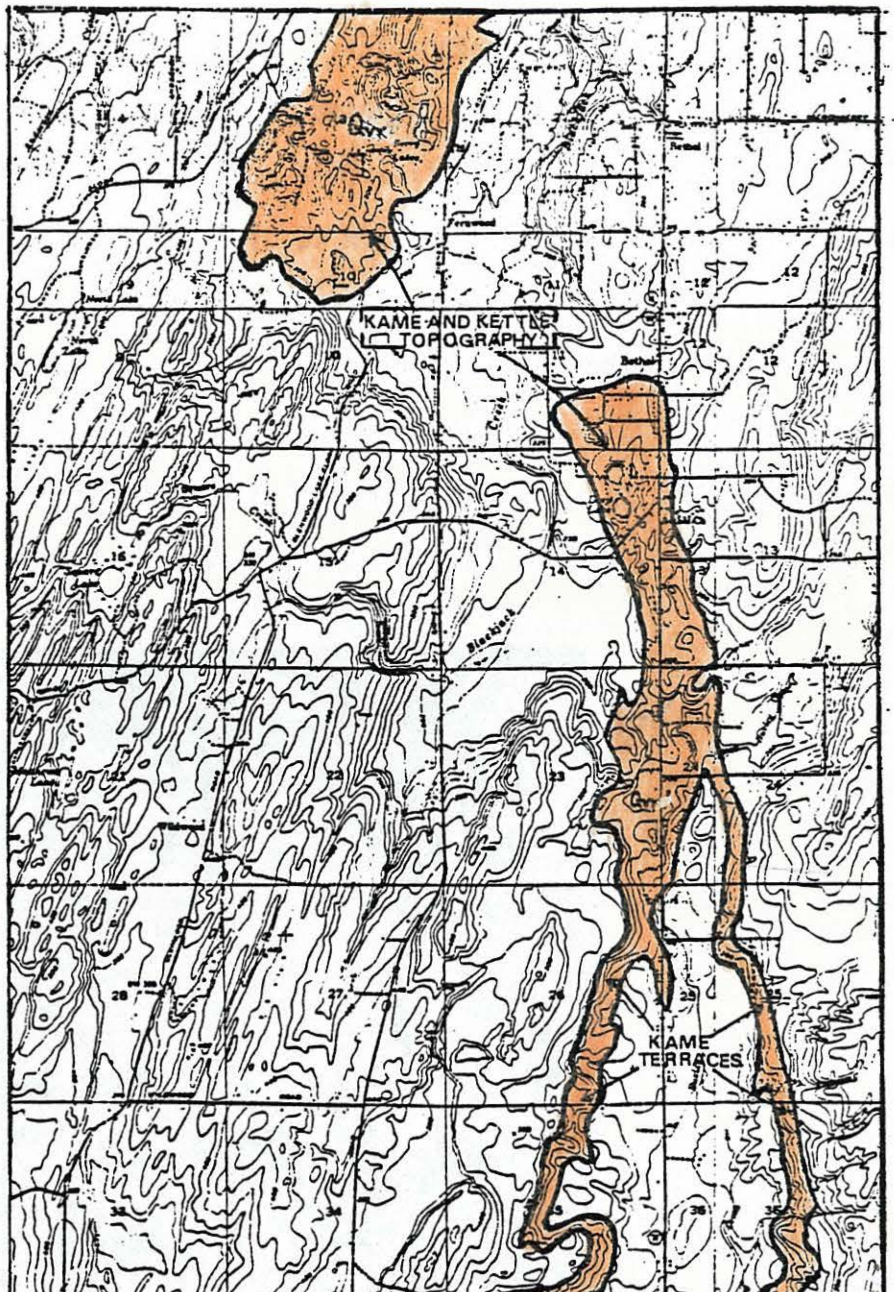


Figure 60 SCALE 1:62,500

N

Vashon ice contact deposits adjacent to Blackjack and Burley Valley.

Numerous deltaic deposits formed during deglaciation by sediment-laden outwash streams show good foreset and topset beds and consist of well sorted sand and gravel. Thicknesses of deltaic deposits in Kitsap County ranges from 10 to 20 meters.

Deltaic deposits near Breidablick in the northwest part of the county (sec. 26 and 27, T. 27 N., R. 1 E.) consist of sand and gravel deposited by meltwater streams (Figure 61). Foreset beds in the sand and gravel dip 31^{o} to 35^{o} to the northwest, indicating direction of stream flow was to the northwest during deglaciation (Figure 62). A deltaic deposit southeast of Lemola (sec. 31, T. 26 N., R. 2 E) shows foreset beds of sand and gravel that dip due-south to 56^{o} west, indicating stream drainage was from north to south.

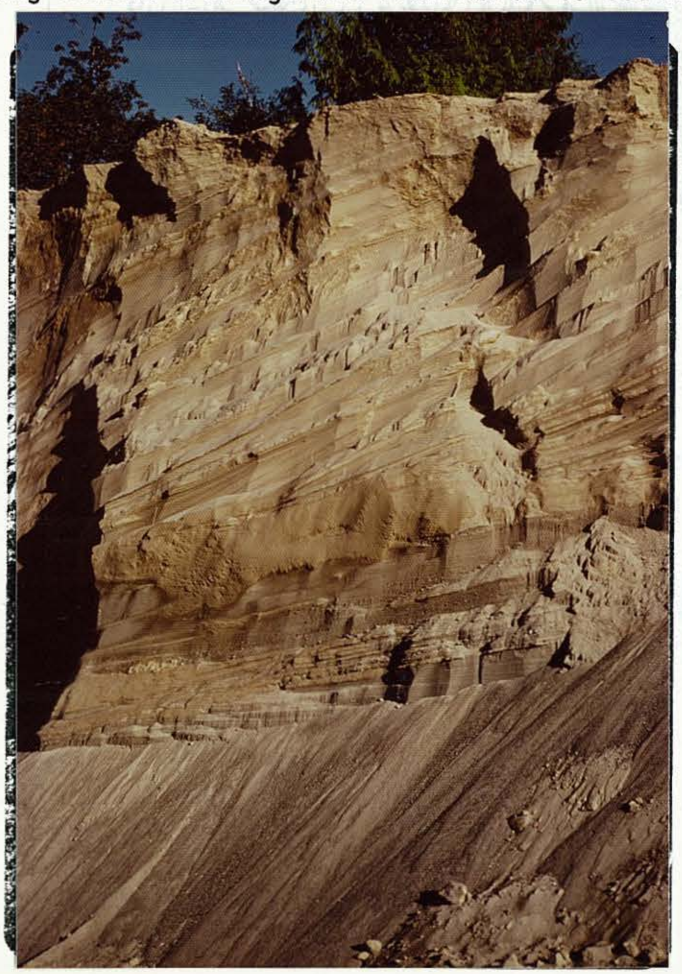
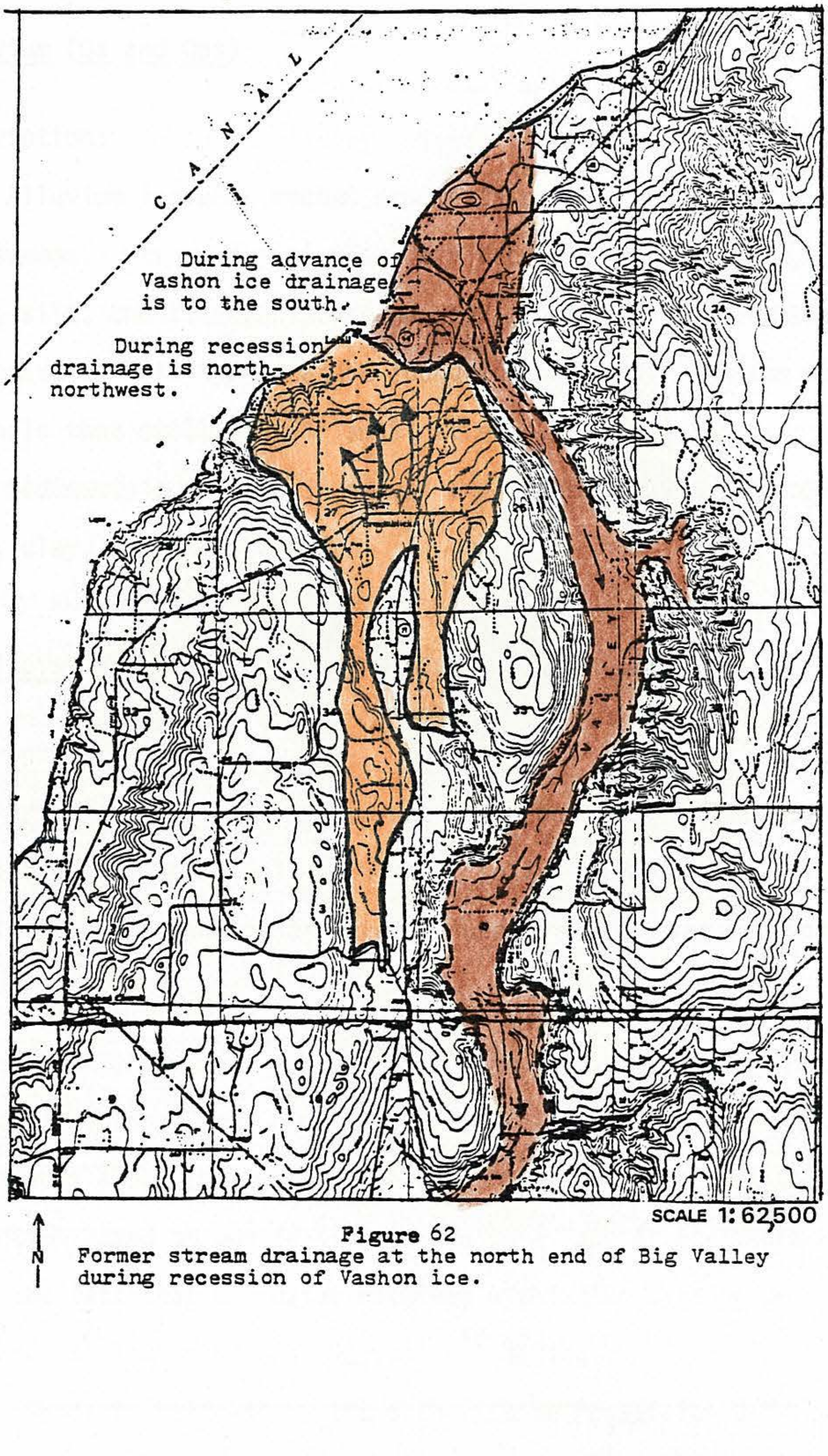


Figure 61. Deltaic sand deposit northeast of Breidablick in sec. 26, T. 27 N., R. 1 E.



SCALE 1:62,500

N

Figure 62
Former stream drainage at the north end of Big Valley during recession of Vashon ice.

Holocene

Alluvium (Qa and Qps)

Description:

Alluvium includes recent sediments deposited in streams, lakes and swamps. Stream deposits are divided into two types: (1) (Qa_2) clay, silt, and fine-grained sand, and (2) (Qa_1) coarse-grained sand and gravel. Both types can be found in many of the former outwash channels that still contain small streams.

Sediments deposited in swamps and lakes (Qps) consist of mostly peat, clay, and silt.

Artificial Fill (af)

Description:

Artificial fill is mapped where man has modified the topography by placing a substantial addition of soil, sediment, rock, vegetative debris, garbage, and other material upon pre-existing surfaces.

SUMMARY OF CONCLUSIONS

Evidence in Kitsap County indicates at least two and possibly three major glaciations. The oldest glacial unit is correlative with the Double Bluff Drift on Whidbey Island, whereas the youngest till corresponds to the Vashon Drift. Correlation of the oldest pre-Vashon Drift in Kitsap County with the Double Bluff Drift on Whidbey Island is based on: (1) similar characteristics of the tills, and (2) a thick sequence of nonglacial, fine-grained, floodplain deposits overlying the tills.

The Possession Drift on Whidbey Island, which represents a glaciation between the Double Bluff and Fraser Glaciations is distinguished from the latter on the basis of radiocarbon dates and its stratigraphic position. C^{14} dates obtained above the Possession on Whidbey Island are between 35,000 and 28,000 years B.P., whereas dates below the Possession have been beyond the limits of conventional C^{14} dating techniques. Also the stratigraphic sequence on Whidbey Island places the Whidbey Formation below the Possession, while the Quadra Formation of the Olympia nonglacial interval overlies the Possession.

In Kitsap County evidence for glaciation between the Double Bluff and Fraser Glaciation is very vague. Oxidized gravel in the south portion of the county near Maplewood may represent Possession Drift as does crossbedded sand containing granitic stones found at several locations along the eastern shoreline of the county. An accurate distinction based on age is limited due to a lack of stratigraphic evidence and the fact that C^{14} dates obtained within the sand or gravel are beyond the limits of conventional C^{14} dating.

Deposits believed by the author to be Possession Drift are tentatively mapped as such until a more thorough investigation can be made.

Floodplain sediments of the Kitsap Formation overlie Possession Drift, which, according to Molenaar (Garling and others, 1965), belong to the Olympia nonglacial interval. At the type locality of the Kitsap Formation near Maplewood, Molenaar included oxidized gravel that are interbedded with clay, silt, sand, and peat as part of the Kitsap Formation. Based on stratigraphic correlation and C^{14} dates, the author concludes that Molenaar's Kitsap Formation is a "catch-all" term which includes the Whidbey Formation, Possession Drift, and Olympia nonglacial sediments. The Whidbey Formation and Olympic nonglacial sediments consist of interbedded, fine-grained sand, silt, clay, and peat deposited in a floodplain environment and are usually well bedded. Distinguishing between nonglacial units is difficult because of similar environments of deposition and pinching out of Possession Drift between the Kitsap and the Whidbey Formations. C^{14} dating can be used as a criterion in distinguishing the two nonglacial units. C^{14} dates of Olympia nonglacial sediments in Kitsap County have ranged between 15,350 ± 210 years B.P. (I-10,374) and 36,235 ± 2680 years B.P. (U.W.-446), whereas C^{14} dates on material from Whidbey Formation sediments are beyond the limits of conventional C^{14} dating techniques. In almost all instances, sediments of the Whidbey Formation extend upward from beach level to higher elevations than adjacent floodplain deposits of the Olympia nonglacial interval, suggesting the Whidbey floodplain was extensively eroded, possibly during subsequent overriding by ice during the Possession Glaciation and prior to deposition of the Olympia floodplain sediments which are unconformable upon the irregular surface of the Whidbey Formation. A complete summary of geologic events which occurred during the Quaternary Period is shown in Table 7.

Table 7

QUATERNARY GEOLOGIC HISTORY OF THE PUGET LOWLAND
IN KITSAP COUNTY

(Based on data from Sceva (1957), Crandell (1965), Mullineaux and others (1965), Molenaar (Garling and others, 1965), Easterbrook and others (1967), Easterbrook (1969), Hansen and Easterbrook (1974).)

SYSTEM	SERIES	C^{14} AGE in Years B.P.	GEOLOGIC CLIMATE UNITS AND CLIMATIC EVENTS	GEOLOGIC EVENTS	STRATIGRAPHIC UNIT
QUATERNARY	HOLOCENE			Soils developed in upper meter on many of the Pleistocene deposits. Deposition of sediments in streams, lakes, bays, lagoons, etc. took place in basins and on flood plains. Marine deposition formed spits and bars. Stream and wave erosion as well as landslides and weathering began reshaping the land. Swamps and peat bogs occupied numerous depressions on till surface.	Alluvium
		10,000 ?			
	PLEISTOCENE	13,350	Climate becoming milder. Fraser Glaciation Vashon Stade	Marine waters invade Puget Lowland. Sediment and large quantities of meltwater were produced by melting of the ice. Sediment released from the ice and reworked earlier drift was deposited as ice-contact and proglacial stratified drift. Deltaic deposits common. Some drainage during this period of time is to the north as a result of differences in topography underlying the ice.	Vashon Drift: Recessional outwash
				Ice was 900 to 1200m thick in the Kitsap Peninsula area.	Vashon Drift: Till
				Advance outwash sand and gravel of Esperance sand unit is deposited. Finer-grained sediment was deposited some distance from the ice front, whereas coarser material was deposited closer, filling the proglacial lakes.	Vashon Drift: Esperance sand
		15,000	-Climate becoming cooler prior to arrival of ice.	Proglacial lakes formed as a result of the Puget Lobe blocking drainage through Straits of Juan de Fuca. Massive silt and clay was deposited in these lakes. Cordilleran ice sheet formed in the Coast Range and in southwest British Columbia.	Vashon Drift: Proglacial lacustrine sediments
		15,350			
		16,510	-Climate cooler and more moist than present. Olympia Nonglacial Interval	Prior to the advance of the Puget Lobe into Lowland, alpine glaciers advanced and retreated in the Olympics. Meltwater streams from these flow across Hood Canal and deposit coarse, reddish gravel along west shoreline of Kitsap Peninsula. Some interfingering of this gravel with the fine-grain sediments of the Kitsap Formation occurs.	Skokomish Gravel
		36,235		Deposition of lacustrine and fluvial sediment of Kitsap Formation began soon after Possession ice retreated from the Puget Lowland.	Kitsap Formation
		38,000	Possession Glaciation -Cooler, more moist climate than present.	Advance and recession of Puget Lobe near north tip of Kitsap Peninsula. Outwash from glacier consisting of oxidized sand and gravel is deposited in southeast Kitsap County. Minor recession of ice to the north results in deposits of interbedded fine-grained sand, silt, and peat between the oxidized gravels.	Possession Drift
		71,500	?------?------?------?------?	?------?------?------?------?------?------?------?------?	---?---?---
	PLEISTOCENE		Climate similar to present. Whidbey Interglaciation	Meltwater streams from Alpine glaciers in the Olympics flow across Hood Canal, depositing extensive sand and gravel. Floodplain deposits consisting of interbedded fine-grained sand, silt, clay, and peat with some localized gravel lenses were deposited. Silt and sand were deposited on extensive floodplains and deltas. Peat beds interbedded with fine-grained sediment represent organic material deposited in swampy areas on the floodplain. Erosion began reshaping land surface when ice receded from Lowland. May be correlative with Puyallup Interglaciation in southern Puget Lowland.	Whidbey Formation
QUATERNARY			-Climate becoming milder. Double Bluff Glaciation -Cooler climate.	During late stages of glaciation, marine waters invaded the Lowland. Floating or calving of ice at the glacier's front caused deposition of pebbly, silty glaciomarine drift containing shells of marine organisms. Melting ice produces large quantities of water: meltwater streams deposit gravel. Lodgement till up to 30m thick is deposited in Kitsap County. Ice advanced into Lowland, reshaping the land surface. Tongues of ice advanced into former valleys, deepening some and filling others. Cordilleran ice formed in the Coast Range and in southwest British Columbia. May be correlative with Stuck Glaciation in southern Puget Lowland.	Double Bluff Drift

APPENDICES

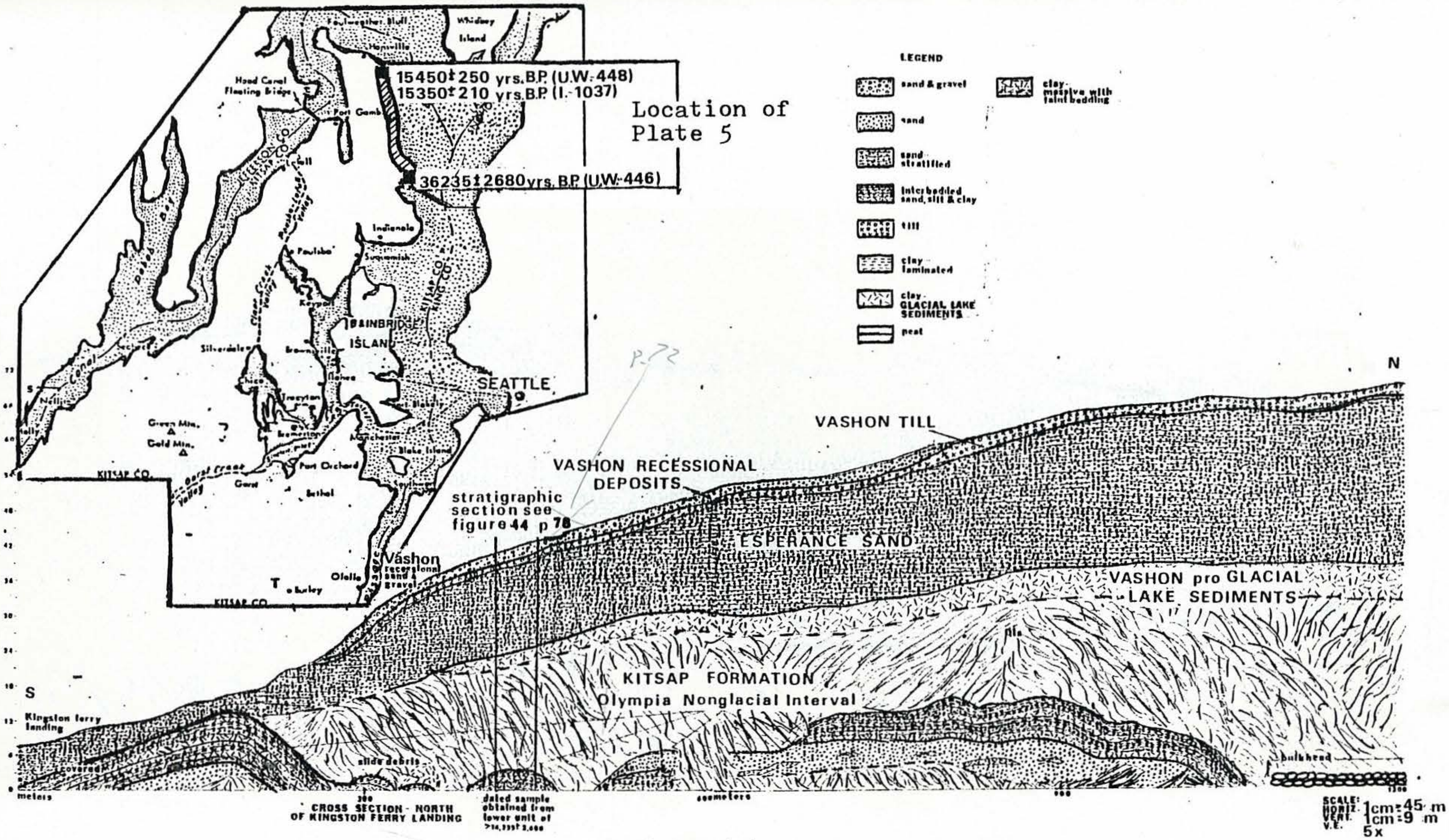


Plate 5.1
<u>Plate 5</u> includes Plates 5.1 through 5.12 and is a stratigraphic cross-section from Kingston north to Point-No-Point.

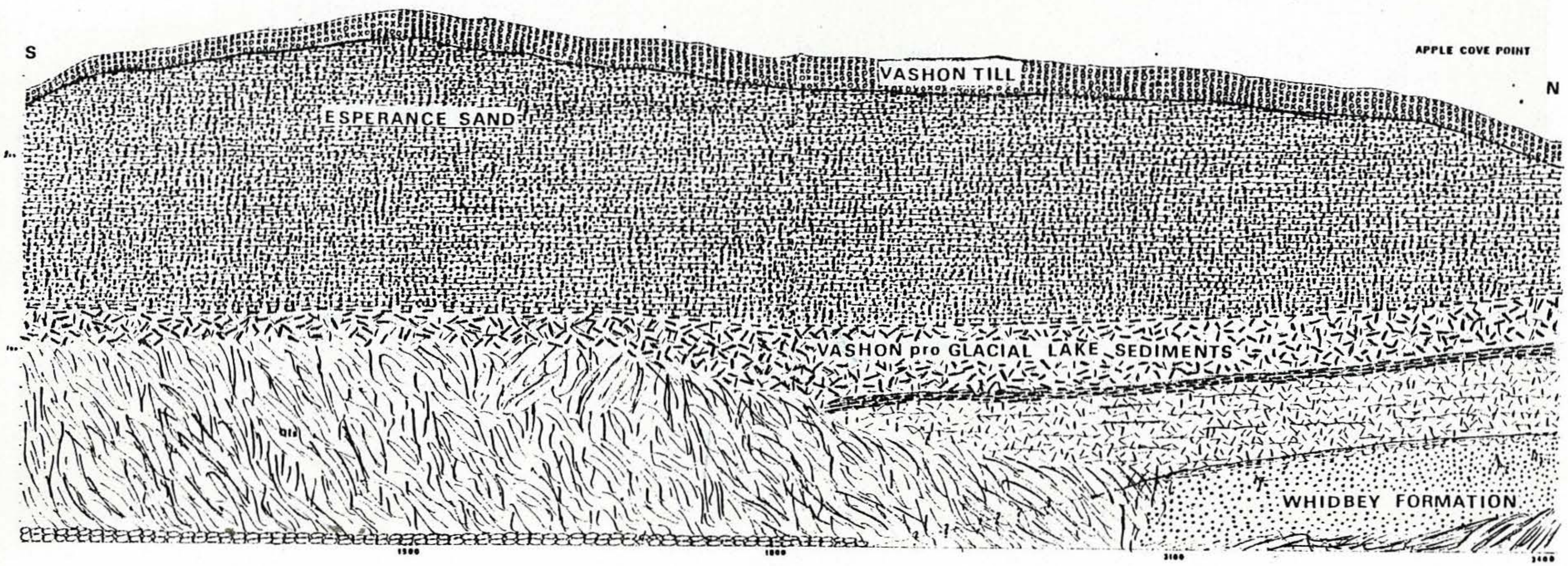

S
APPLE COVE POINT
N
VASHON TILL
ESPERANCE SAND
VASHON pro GLACIAL LAKE SEDIMENTS
WHIDBEY FORMATION

Plate 5.2

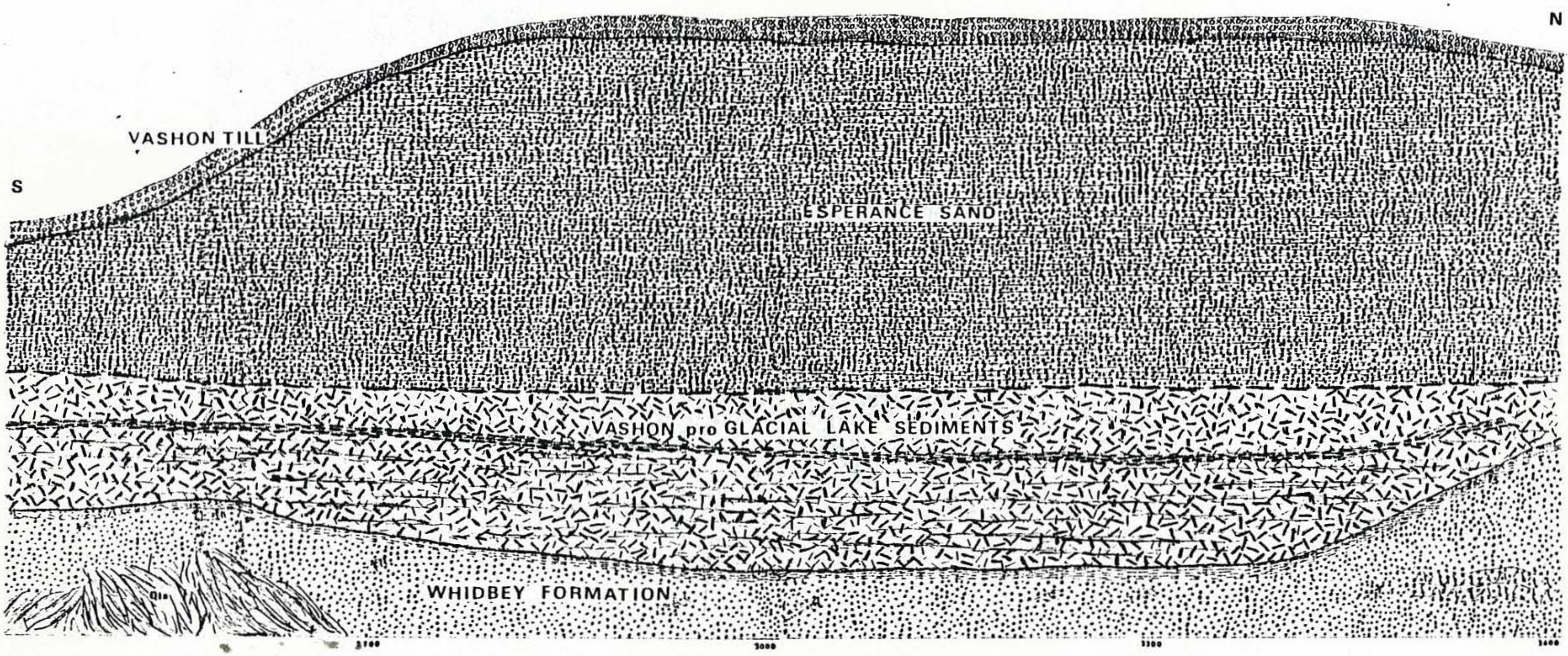

N
VASHON TILL
S
ESPERANCE SAND
VASHON pro GLACIAL LAKE SEDIMENTS
WHIDBEY FORMATION

Plate 5.3

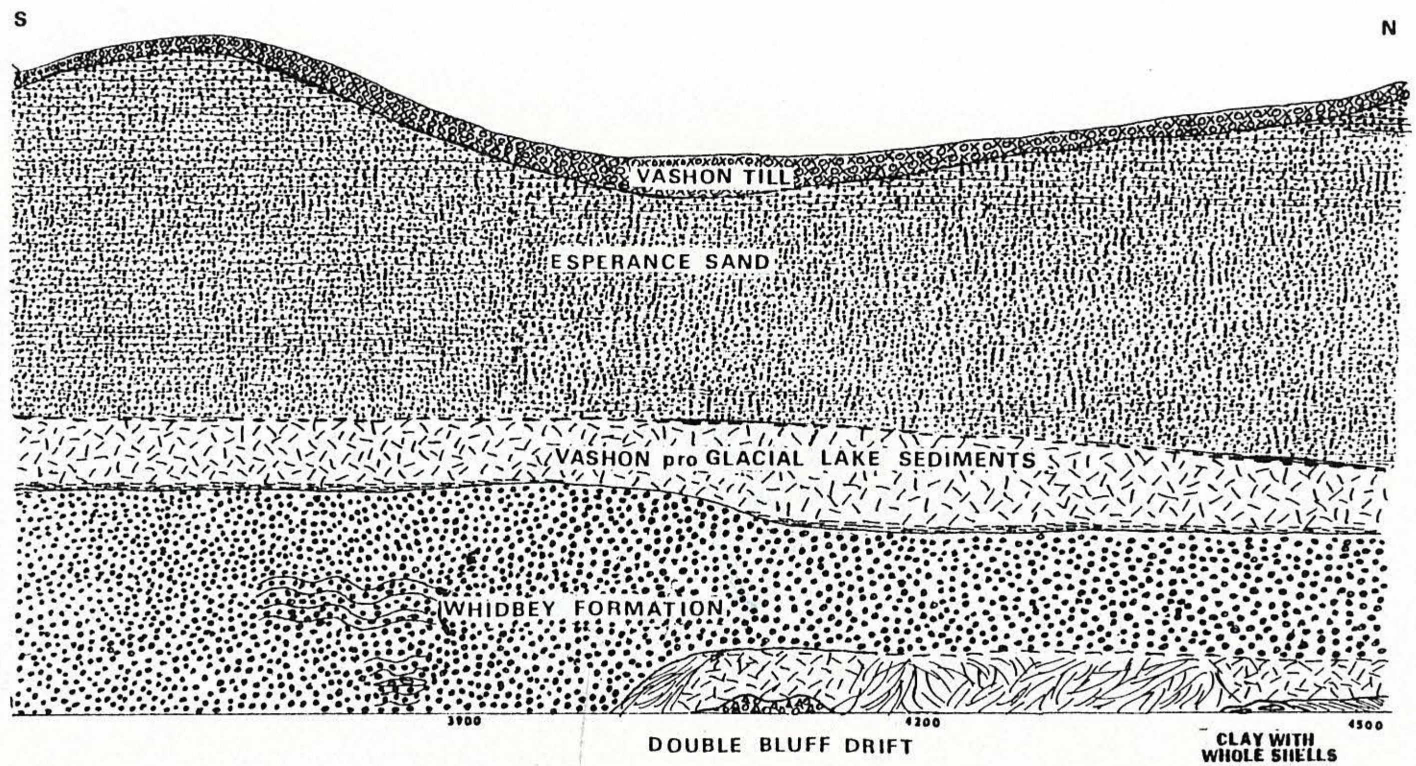

S
N
VASHON TILL
ESPERANCE SAND
VASHON pro GLACIAL LAKE SEDIMENTS
WHIDBEY FORMATION
3900
4200
4500
DOUBLE BLUFF DRIFT
CLAY WITH
WHOLE SHELLS

Plate 5.4

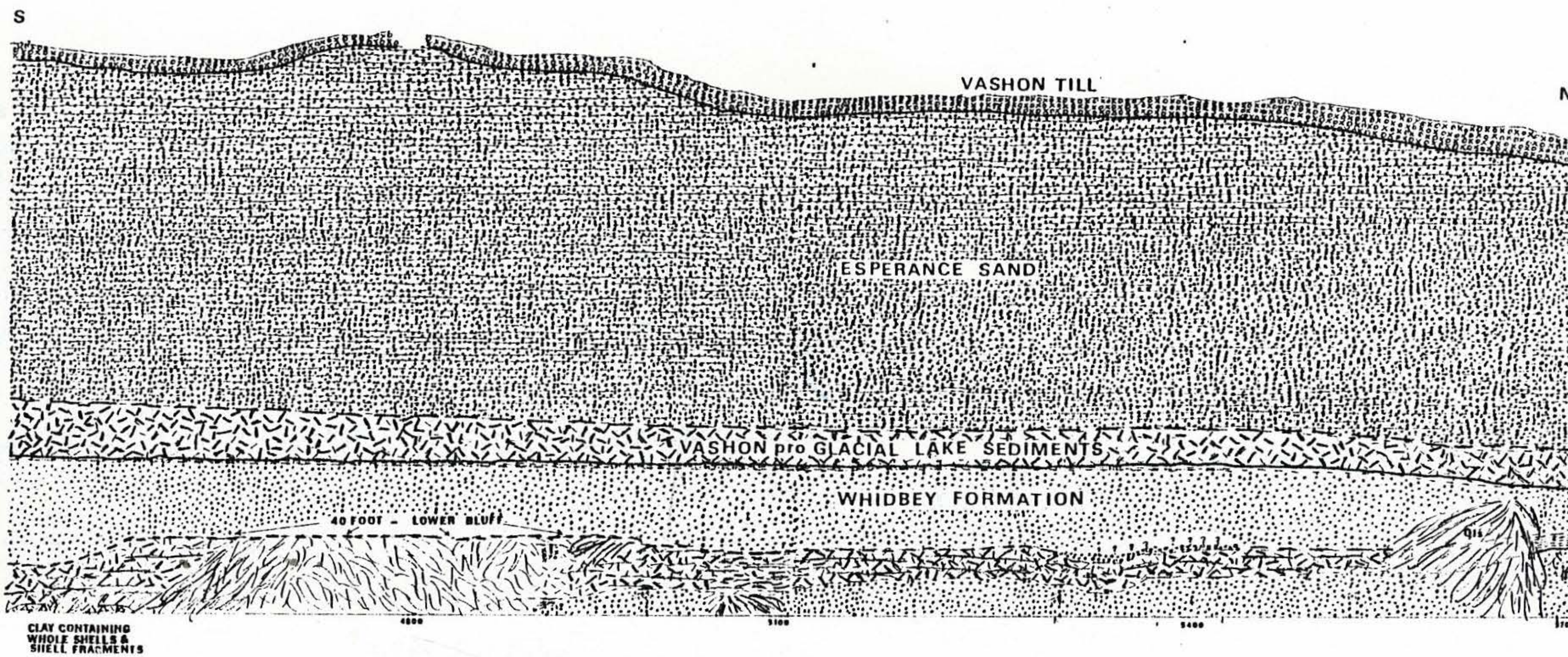

S
N
VASHON TILL
ESPERANCE SAND
VASHON pro GLACIAL LAKE SEDIMENTS
WHIDBEY FORMATION
40 FOOT - LOWER BLUFF
CLAY CONTAINING WHOLE SHELLS & SHELL FRAGMENTS

Plate 5.5

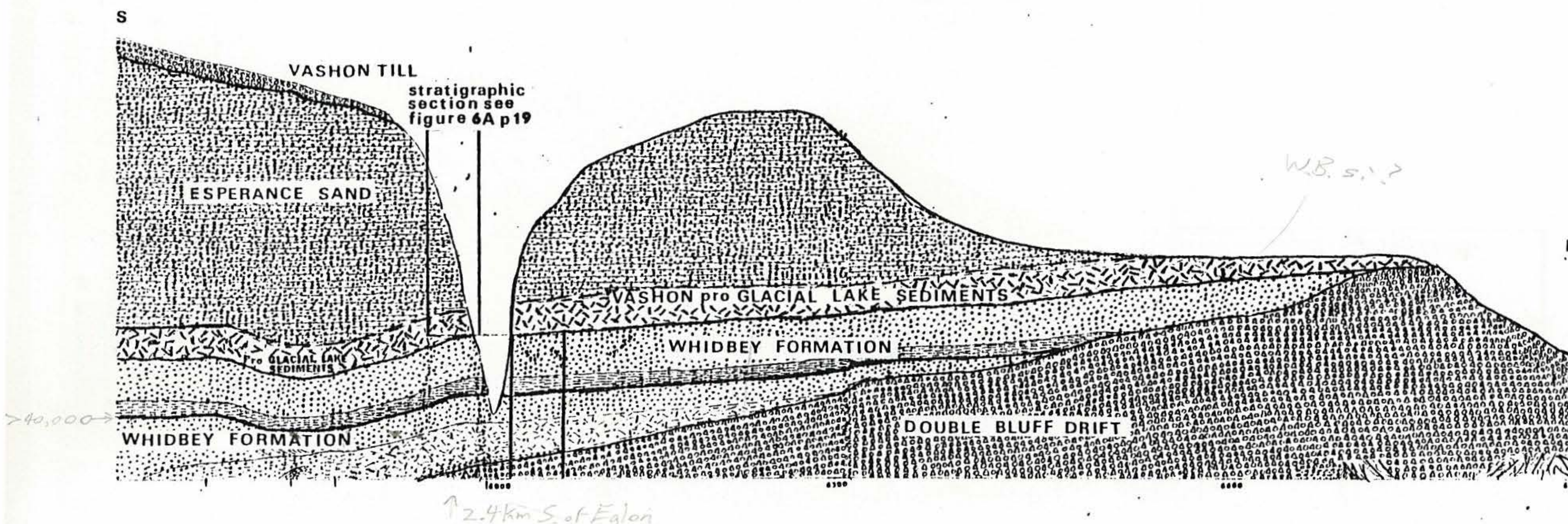

S
VASHON TILL
stratigraphic section see figure 6A p19
ESPERANCE SAND
VASHON pro GLACIAL LAKE SEDIMENTS
pro GLACIAL LAKE SEDIMENTS
WHIDBEY FORMATION
WHIDBEY FORMATION
DOUBLE BLUFF DRIFT
N
>40,000
2.4 km S. of Eglon

Plate 5.6

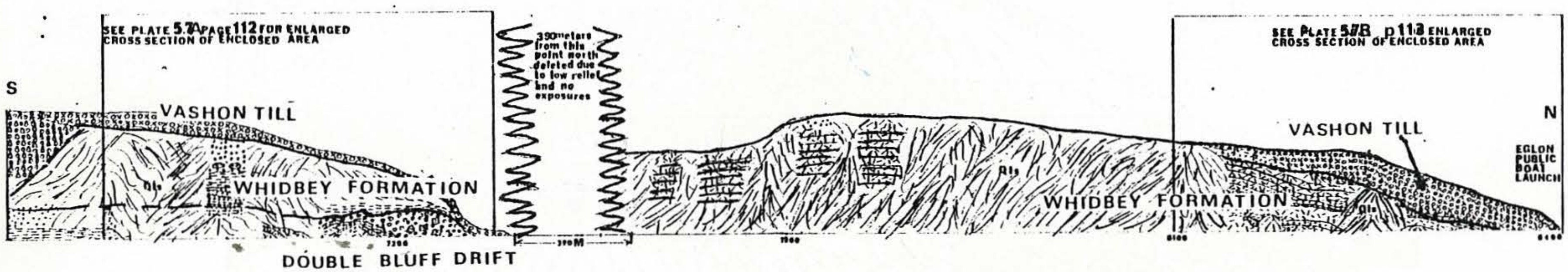

SEE PLATE 5.7A PAGE 112 FOR ENLARGED
CROSS SECTION OF ENCLOSED AREA
S
VASHON TILL
WHIDBEY FORMATION
DOUBLE BLUFF DRIFT
390 meters from this point north deleted due to low relief and no exposures
390M
SEE PLATE 5.7B p113 ENLARGED
CROSS SECTION OF ENCLOSED AREA
N
VASHON TILL
WHIDBEY FORMATION
EGLON
PUBLIC
BOAT
LAUNCH

Plate 5.7

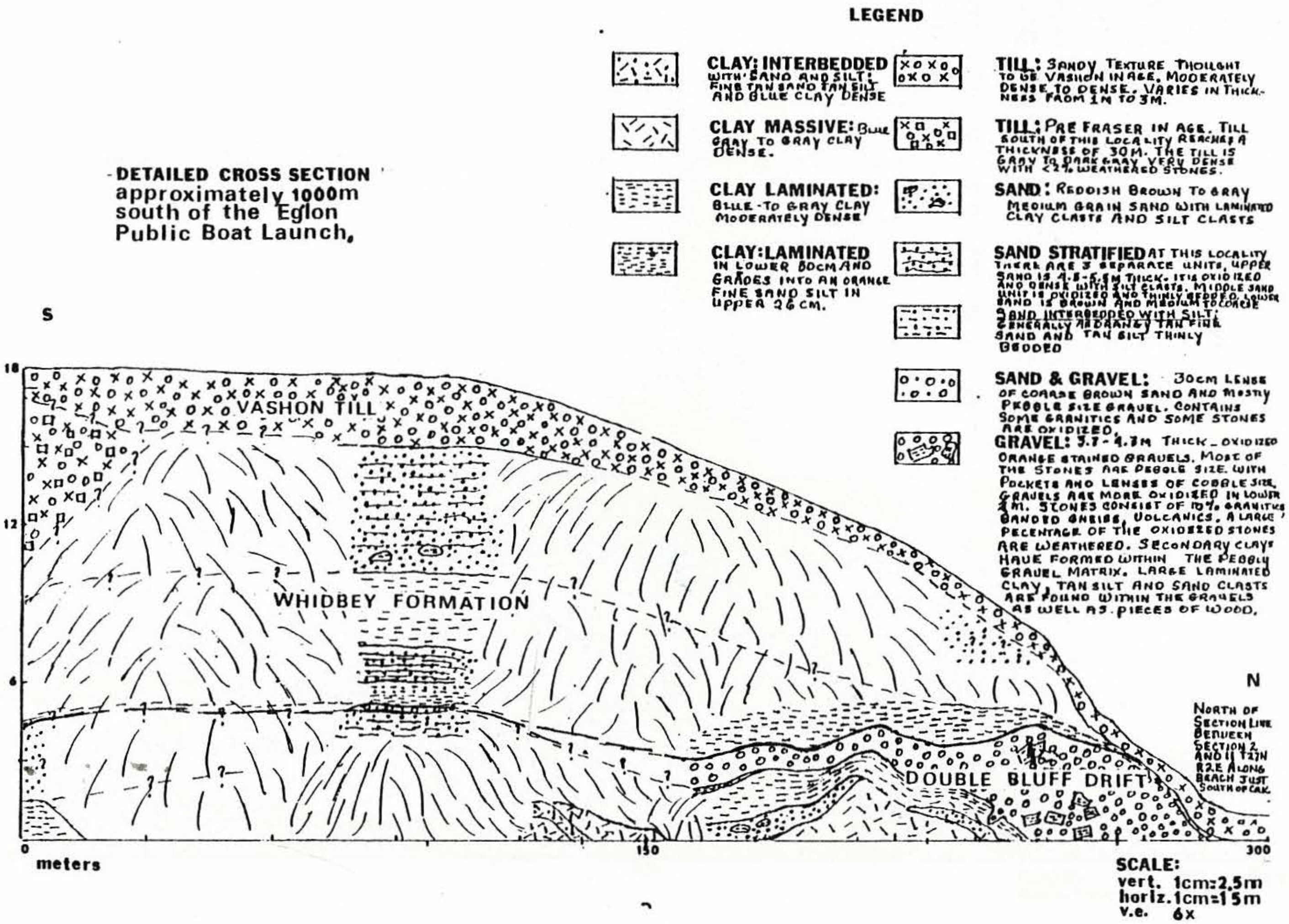
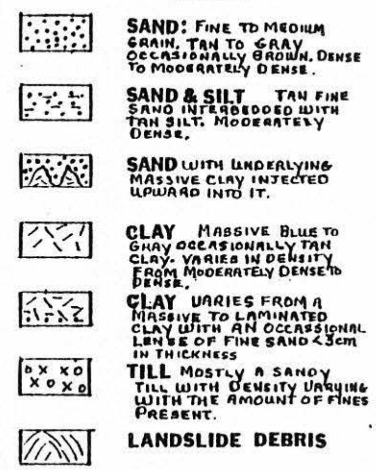

DETAILED CROSS SECTION
approximately 1000m south of the Eglon Public Boat Launch,
LEGEND
CLAY: INTERBEDDED WITH SAND AND SILT: FINE TAN SAND TAN SILT AND BLUE CLAY DENSE
CLAY MASSIVE: BLUE GRAY TO GRAY CLAY DENSE.
CLAY LAMINATED: BLUE-TO GRAY CLAY MODERATELY DENSE
CLAY:LAMINATED IN LOWER 80CM AND GRADES INTO AN ORANGE FINE SAND SILT IN UPPER 26 CM.
TILL: SANDY TEXTURE THOUGHT TO BE VASHON IN AGE. MODERATELY DENSE TO DENSE. VARIES IN THICKNESS FROM 1M TO 3M.
TILL: PRE FRASER IN AGE. TILL SOUTH OF THIS LOCALITY REACHES A THICKNESS OF 30M. THE TILL IS GRAY TO DARK GRAY VERY DENSE WITH <2% WEATHERED STONES.
SAND: REDDISH BROWN TO GRAY MEDIUM GRAIN SAND WITH LAMINATED CLAY CLASTS AND SILT CLASTS
SAND STRATIFIED AT THIS LOCALITY THERE ARE 3 SEPARATE UNITS, UPPER SAND IS 4.5-5.5M THICK. IT'S OXIDIZED AND DENSE WITH SILT CLASTS. MIDDLE SAND UNIT IS OXIDIZED AND THINLY BEDDED. LOWER SAND IS BROWN AND MEDIUM TO COARSE
SAND INTERBEDDED WITH SILT: GENERALLY AN ORANGEY TAN FINE SAND AND TAN SILT THINLY BEDDED
SAND & GRAVEL: 30cm LENSE OF COARSE BROWN SAND AND MOSTLY PEBBLE SIZE GRAVEL. CONTAINS SOME GRANITICS AND SOME STONES ARE OXIDIZED.
GRAVEL: 3.7 - 4.7M THICK _ OXIDIZED ORANGE STAINED GRAVELS. MOST OF THE STONES ARE PEBBLE SIZE. WITH POCKETS AND LENSES OF COBBLE SIZE. GRAVELS ARE MORE OXIDIZED IN LOWER 1M. STONES CONSIST OF 10% GRANITICS BANDED GNEISS, VOLCANICS. A LARGE PECENTAGE OF THE OXIDIZED STONES ARE WEATHERED. SECONDARY CLAYS HAVE FORMED WITHIN THE PEBBLY GRAVEL MATRIX. LARGE LAMINATED CLAY, TAN SILT AND SAND CLASTS ARE FOUND WITHIN THE GRAVELS AS WELL AS PIECES OF WOOD.
S
N
18
12
6
0
150
300
meters
VASHON TILL
WHIDBEY FORMATION
DOUBLE BLUFF DRIFT
NORTH OF SECTION LINE BETWEEN SECTION 2 AND 11 T27N R2E ALONG BEACH JUST SOUTH OF CAK.
SCALE:
vert. 1cm:2.5m
horiz. 1cm=15m
v.e. 6x

Plate 5.7A

LEGEND



DETAILED CROSS SECTION
FROM EGLON BOAT LAUNCH SOUTH
APPROXIMATELY 300 M

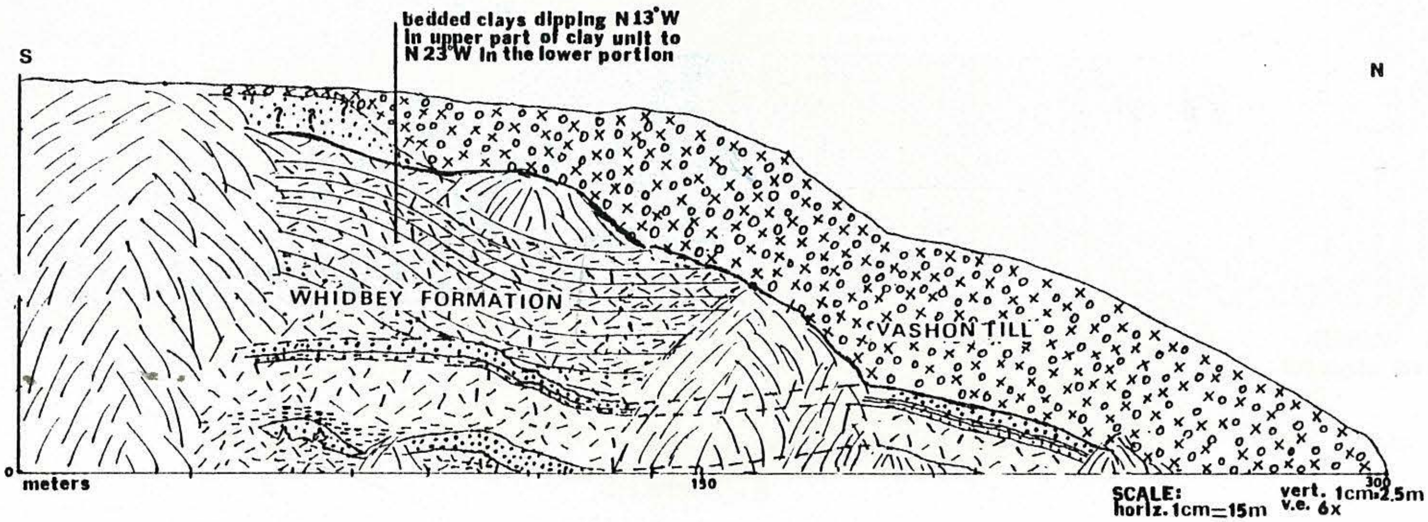


Plate 5.7B

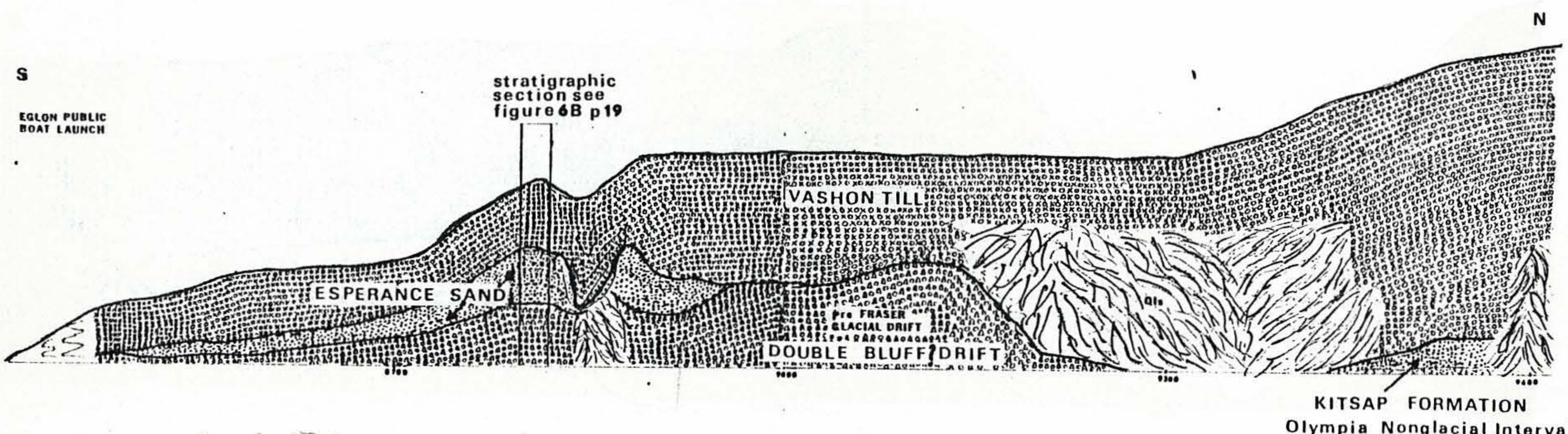

S
EGLON PUBLIC
BOAT LAUNCH
stratigraphic
section see
figure 6B p19
N
VASHON TILL
ESPERANCE SAND
Pre FRASER
GLACIAL DRIFT
DOUBLE BLUFF DRIFT
KITSAP FORMATION
Olympia Nonglacial Interval

Plate 5.8

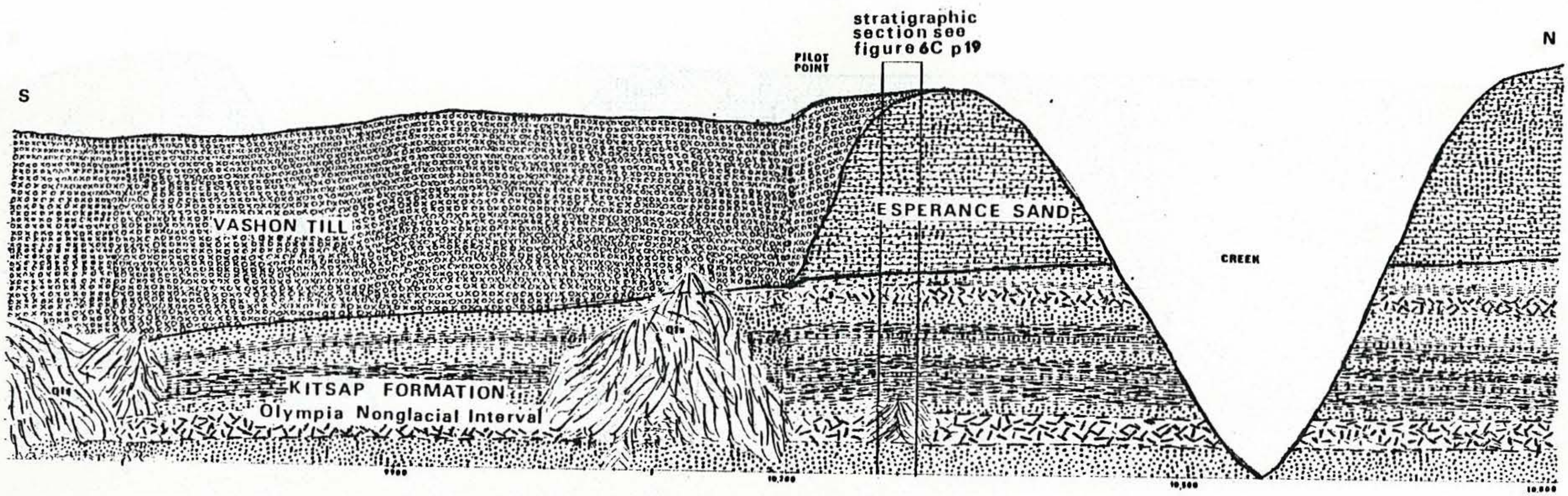

S
N
PILOT POINT
stratigraphic section see figure 6C p19
VASHON TILL
ESPERANCE SAND
CREEK
KITSAP FORMATION
Olympia Nonglacial Interval

Plate 5.9

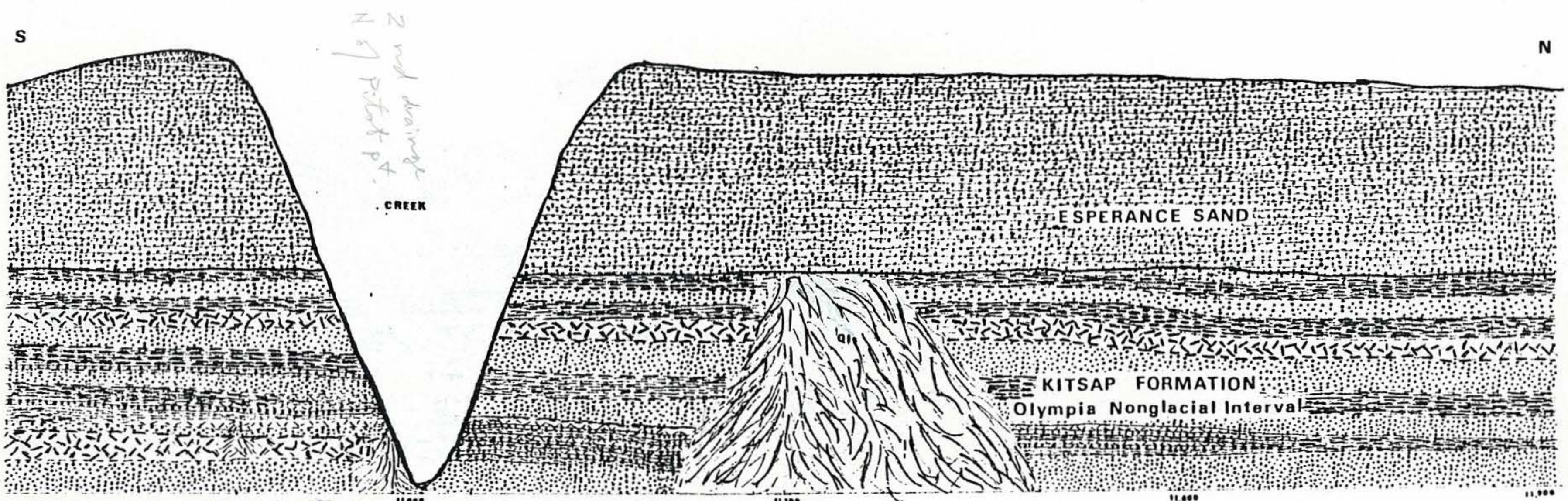

S
N
CREEK
ESPERANCE SAND
KITSAP FORMATION
Olympia Nonglacial Interval

Plate 5.10

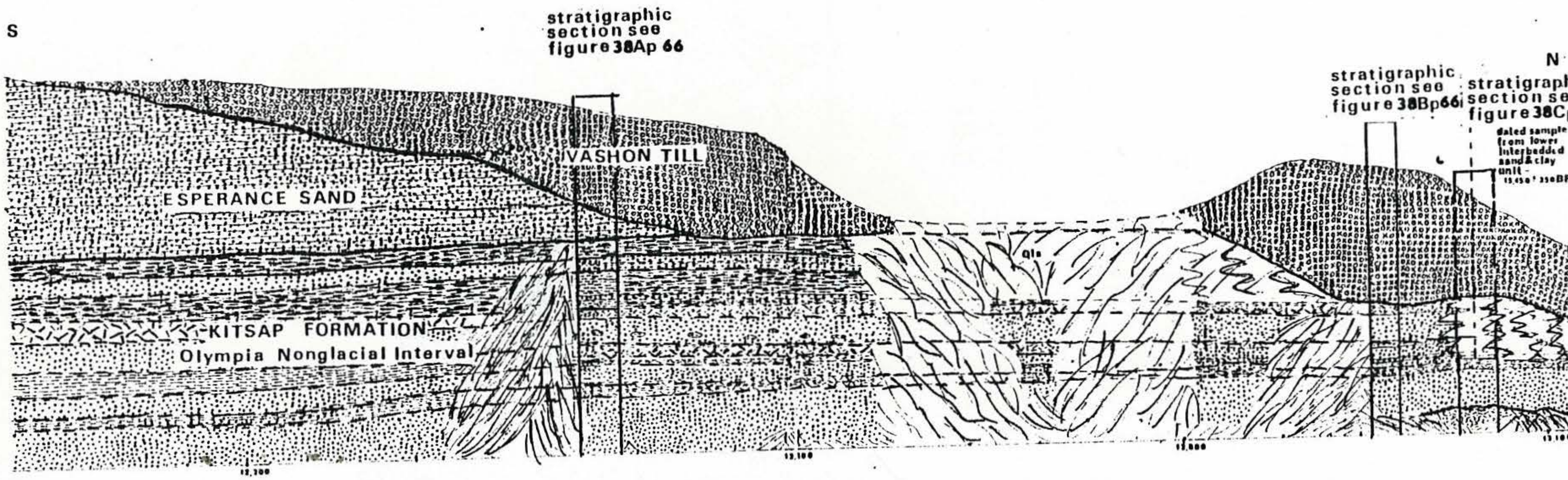

S
stratigraphic section see figure 38A p 66
VASHON TILL
ESPERANCE SAND
KITSAP FORMATION
Olympia Nonglacial Interval
stratigraphic section see figure 38B p 66
N
stratigraphic section see figure 38C p 66
dated sample from lower interbedded sand & clay unit -

Plate 5.11

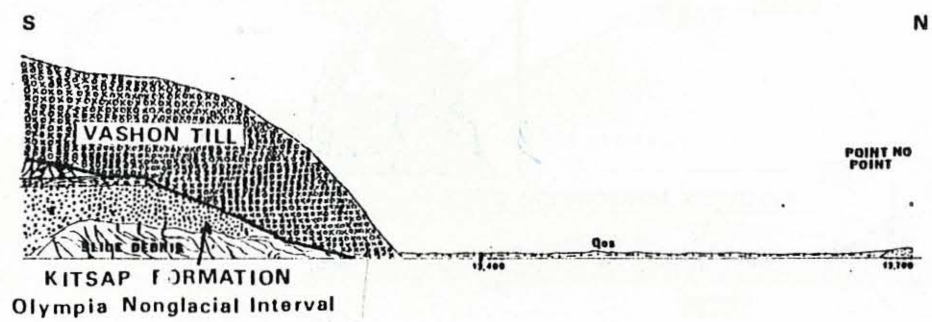

S
N
VASHON TILL
POINT NO POINT
Qos
SLIDE DEBRIS
KITSAP FORMATION
Olympia Nonglacial Interval

Plate 5.12

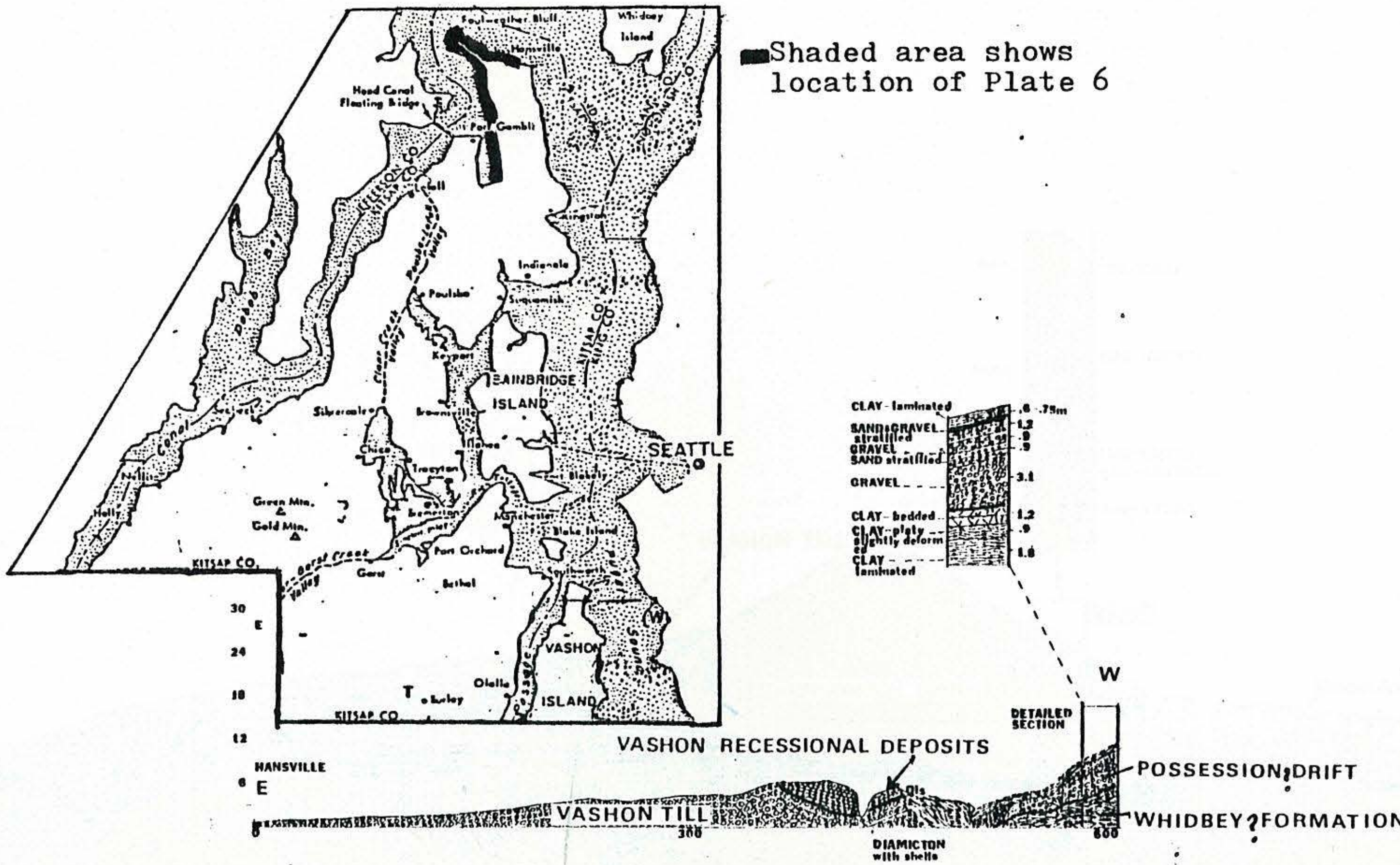


Plate 6.1

Plate 6 includes Plates 6.1 through 6.18 and is a stratigraphic cross-section from Hansville west to Foulweather Bluff and then south to Port Gamble Bay. Approximately two kilometers separates Plate 5.12 and Plate 6.1; therefore, a distinction has been made between this break in the stratigraphic cross-section.

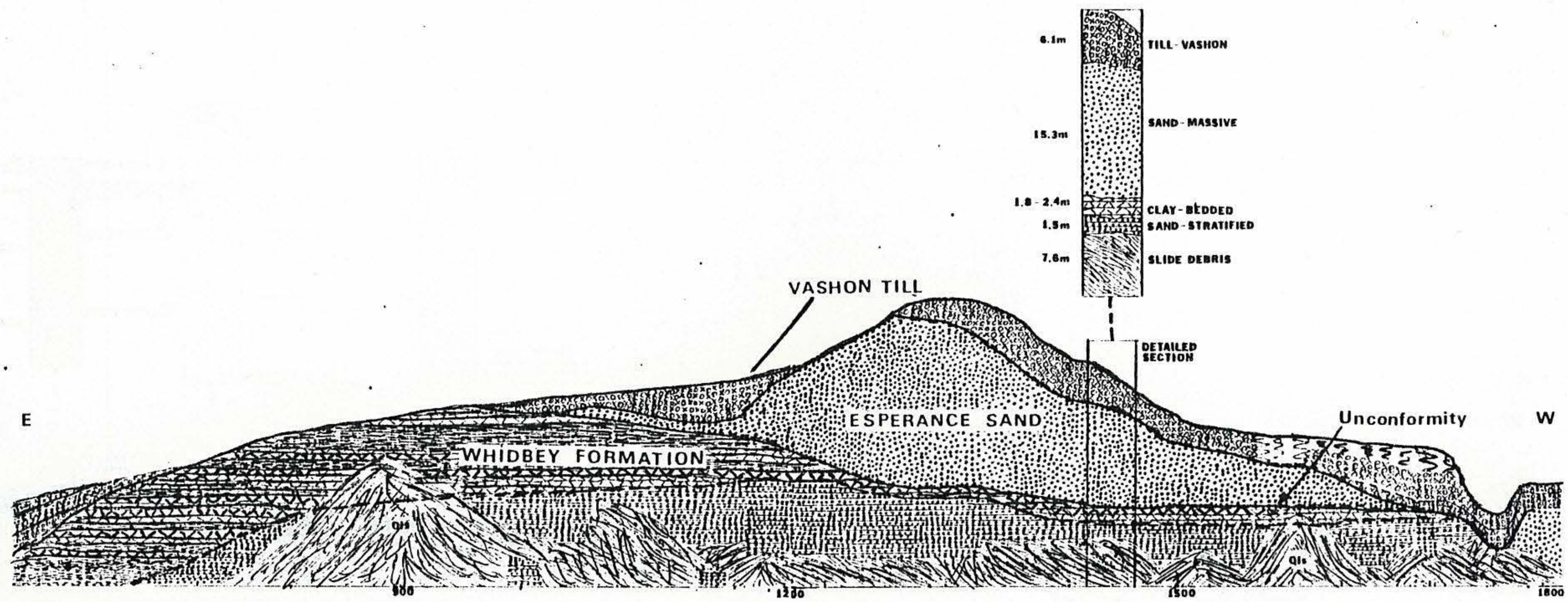

6.1m
TILL-VASHON
15.3m
SAND-MASSIVE
1.8 - 2.4m
CLAY-BEDDED
1.5m
SAND-STRATIFIED
7.6m
SLIDE DEBRIS
VASHON TILL
DETAILED SECTION
E
ESPERANCE SAND
Unconformity
W
WHIDBEY FORMATION
900
1200
1500
1800

Plate 6.2

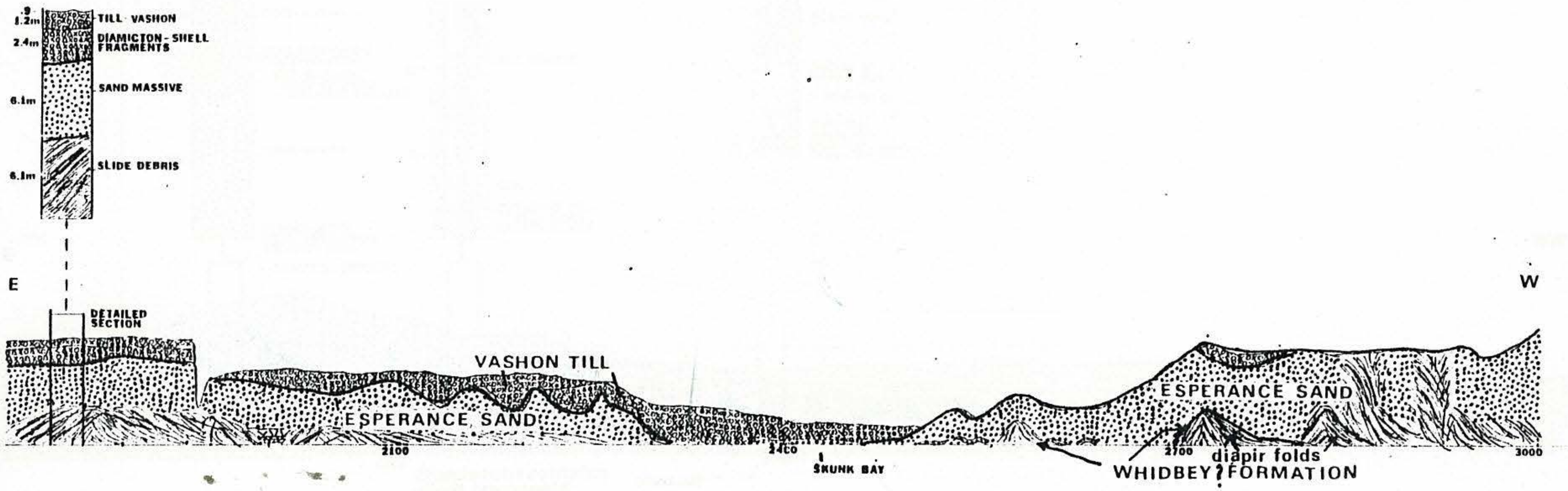

.9
1.2m
TILL VASHON
2.4m
DIAMICTON - SHELL FRAGMENTS
SAND MASSIVE
6.1m
SLIDE DEBRIS
6.1m
E
W
DETAILED SECTION
VASHON TILL
ESPERANCE SAND
ESPERANCE SAND
2100
2400
SKUNK BAY
2700
diapir folds
WHIDBEY?FORMATION
3000

Plate 6.3

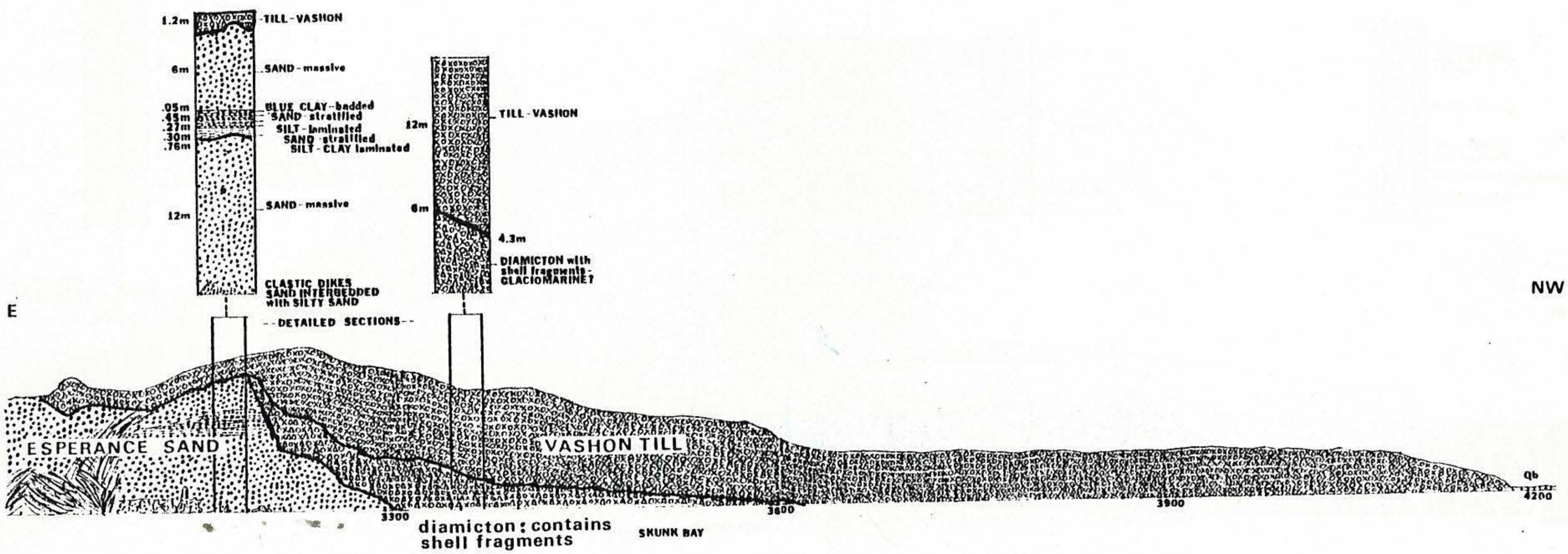

1.2m
TILL - VASHON
6m
SAND - massive
.05m
.45m
.27m
.30m
.76m
BLUE CLAY - badded
SAND stratified
SILT - laminated
SAND stratified
SILT - CLAY laminated
12m
SAND - massive
CLASTIC DIKES
SAND INTERBEDDED
with SILTY SAND
12m
TILL - VASHON
6m
4.3m
DIAMICTON with
shell fragments -
GLACIOMARINE?
- - DETAILED SECTIONS - -
E
NW
ESPERANCE SAND
VASHON TILL
Qb
3300
3600
3900
4200
diamicton: contains
shell fragments
SKUNK BAY

Plate 6.4

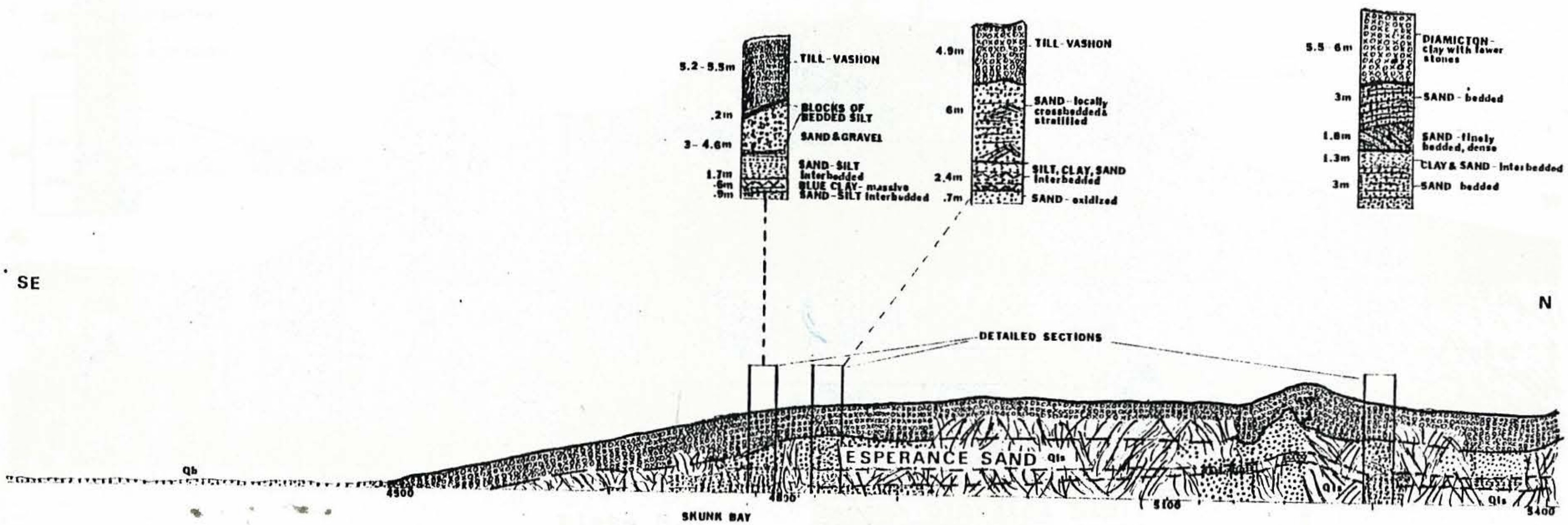

5.2 - 5.5m
TILL - VASHON
.2m
BLOCKS OF BEDDED SILT
3 - 4.6m
SAND & GRAVEL
1.7m
SAND - SILT interbedded
.6m
BLUE CLAY - massive
.9m
SAND - SILT interbedded
4.9m
TILL - VASHON
6m
SAND - locally crossbedded & stratified
2.4m
SILT, CLAY, SAND interbedded
.7m
SAND - oxidized
5.5 - 6m
DIAMICTON - clay with fewer stones
3m
SAND - bedded
1.8m
SAND - finely bedded, dense
1.3m
CLAY & SAND - interbedded
3m
SAND bedded
SE
N
DETAILED SECTIONS
ESPERANCE SAND
Qb
4900
SKUNK BAY
5100
5400

Plate 6.5

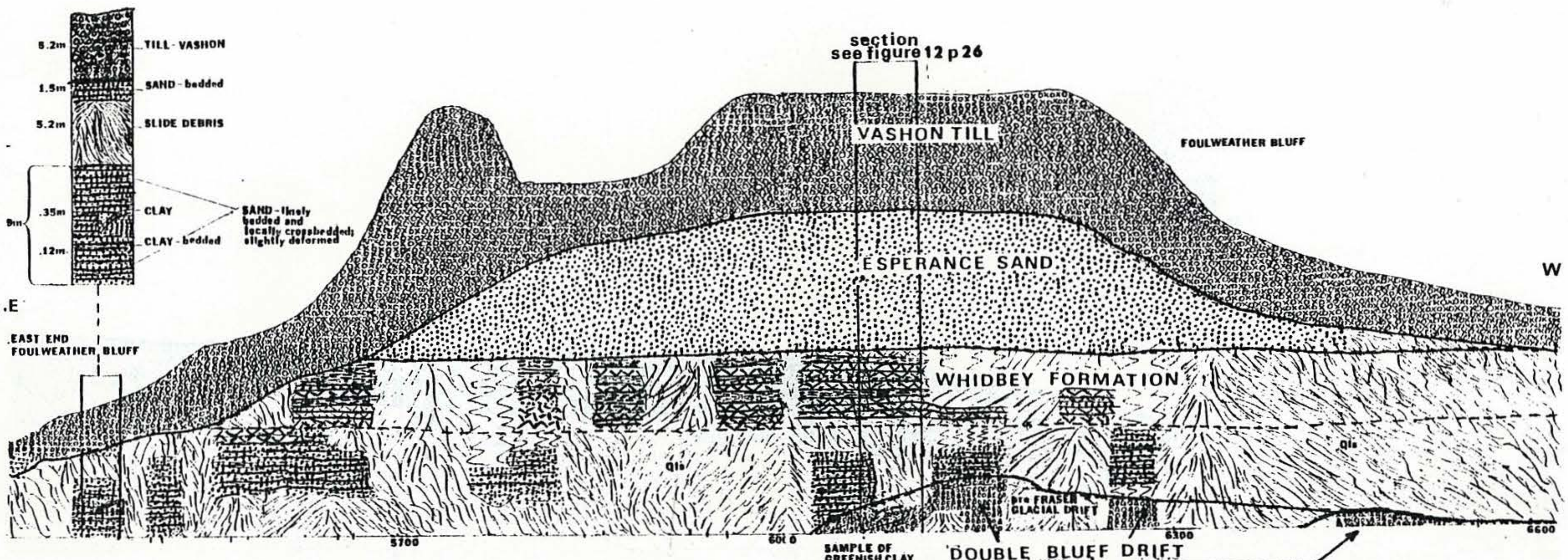


Plate 6.6

Fossil assemblage reported by Bretz (1913) in glaciomarine drift unit at Foulweather Bluff.

<u>Macoma blathica</u> Lin
<u>Macoma calcarea</u> Gmelin.
<u>Macoma</u> (probably young <u>middendorffii</u>, Dall.).
<u>Cardium islandicum</u> Fabr.
<u>Serripes gronlandicus</u> Beck.
<u>Mya truncata</u> Lin., young.
<u>Nucula</u> sp. (like <u>belloti</u> Ads.)
<u>Saxicava artica</u> L.
<u>Leda fossa</u> Baird.
<u>Bela</u> sp ind.

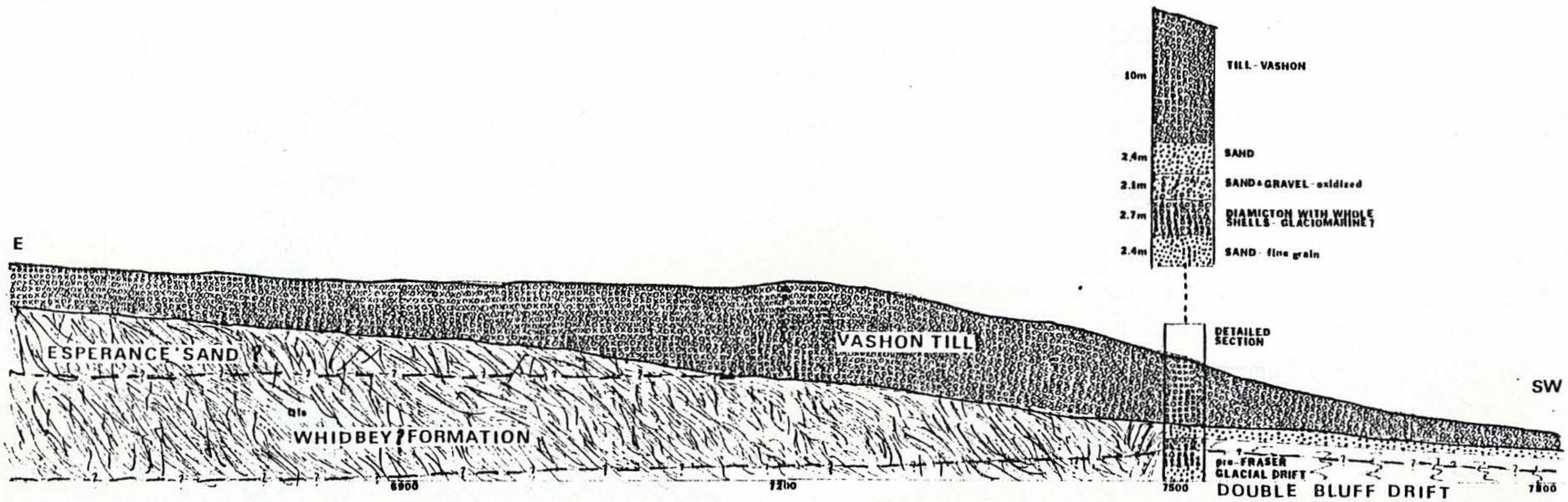
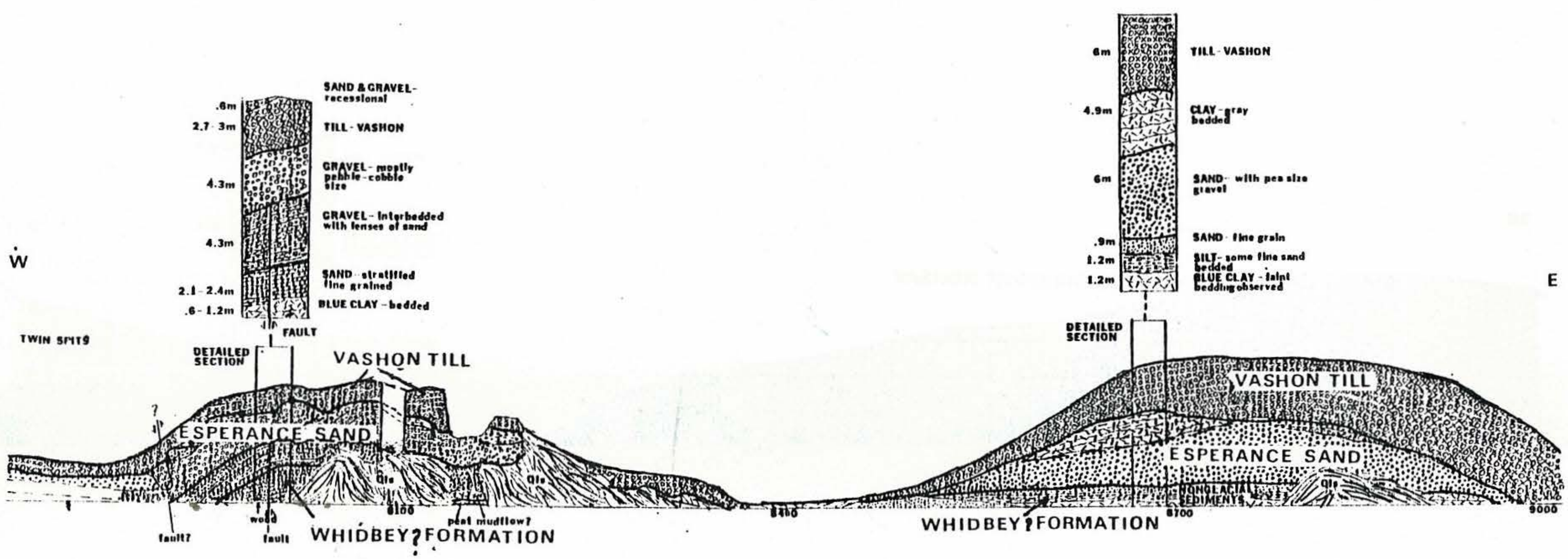

E
SW
10m
TILL - VASHON
2.4m
SAND
2.1m
SAND & GRAVEL - oxidized
2.7m
DIAMICTON WITH WHOLE SHELLS - GLACIOMARINE ?
2.4m
SAND - fine grain
DETAILED SECTION
ESPERANCE SAND ?
VASHON TILL
WHIDBEY ? FORMATION
pre-FRASER GLACIAL DRIFT
DOUBLE BLUFF DRIFT
6900
7200
7500
7800

Plate 6.7



W
SAND & GRAVEL- recessional
.6m
2.7 - 3m
TILL - VASHON
GRAVEL - mostly pebble - cobble size
4.3m
GRAVEL - interbedded with lenses of sand
4.3m
SAND - stratified fine grained
2.1 - 2.4m
.6 - 1.2m
BLUE CLAY - bedded
FAULT
TWIN SPITS
DETAILED SECTION
VASHON TILL
ESPERANCE SAND
wood
fault?
fault
peat mudflow?
WHIDBEY ? FORMATION
6m
TILL - VASHON
4.9m
CLAY - gray bedded
6m
SAND - with pea size gravel
.9m
SAND - fine grain
1.2m
SILT - some fine sand bedded
1.2m
BLUE CLAY - faint bedding observed
E
DETAILED SECTION
VASHON TILL
ESPERANCE SAND
WHIDBEY ? FORMATION
8700
9000

Plate 6.8

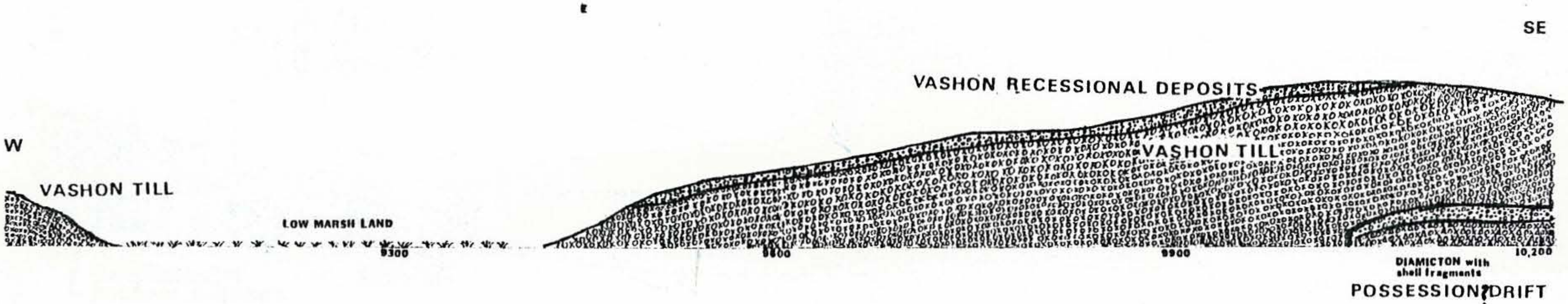

SE
VASHON RECESSIONAL DEPOSITS
W
VASHON TILL
VASHON TILL
LOW MARSH LAND
9300
9900
10,200
DIAMICTON with shell fragments
POSSESSION? DRIFT

Plate 6.9

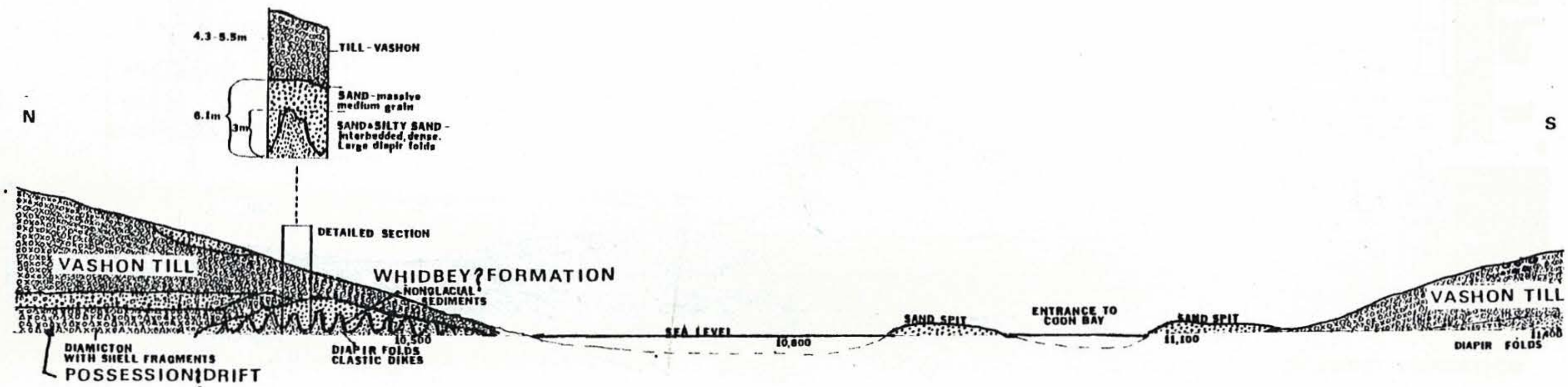
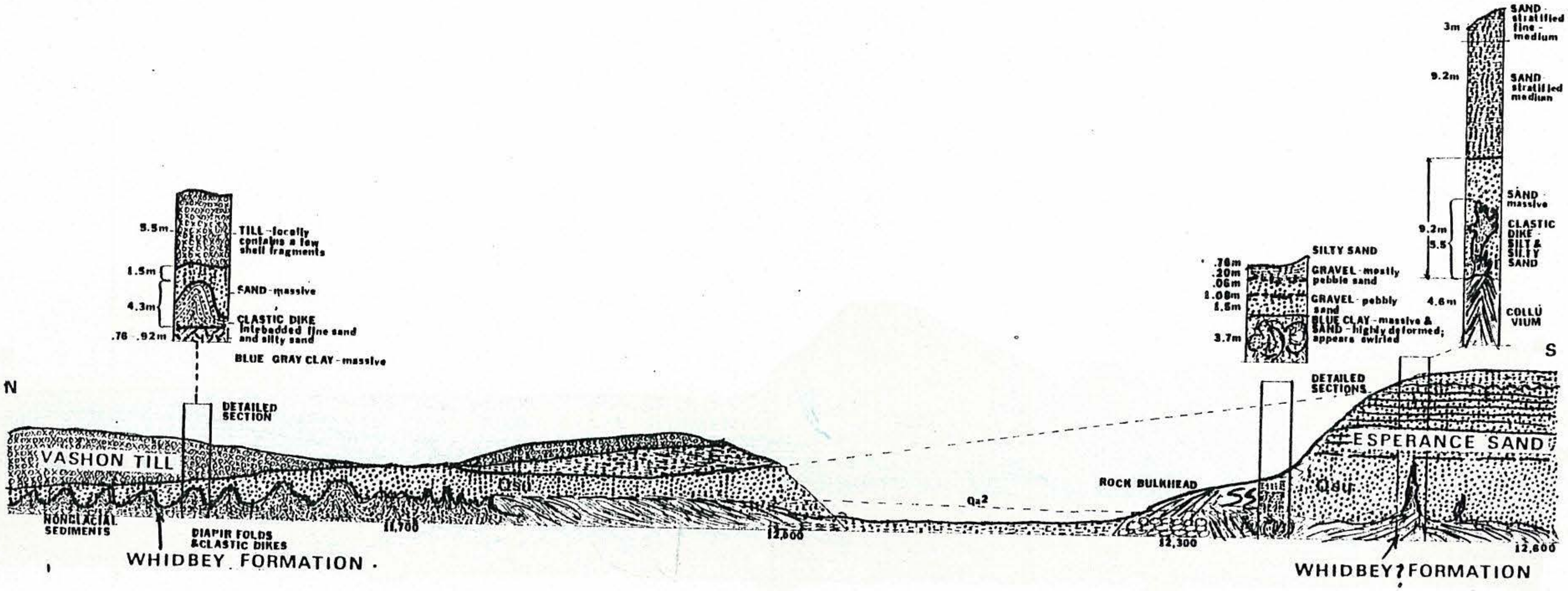

4.3-5.5m
TILL-VASHON
SAND-massive medium grain
6.1m
3m
SAND&SILTY SAND-interbedded, dense. Large diapir folds
N
S
DETAILED SECTION
VASHON TILL
WHIDBEY?FORMATION
NONGLACIAL SEDIMENTS
DIAMICTON WITH SHELL FRAGMENTS
POSSESSION?DRIFT
DIAPIR FOLDS CLASTIC DIKES
10,500
SEA LEVEL
10,800
SAND SPIT
ENTRANCE TO COON BAY
SAND SPIT
11,100
VASHON TILL
11,400
DIAPIR FOLDS

Plate 6.10



TILL - locally contains a few shell fragments
SAND - massive
CLASTIC DIKE
Interbedded fine sand and silty sand
BLUE GRAY CLAY - massive
N
DETAILED SECTION
VASHON TILL
NONGLACIAL SEDIMENTS
DIAPIR FOLDS & CLASTIC DIKES
WHIDBEY FORMATION
11,700
12,000
Qs2
ROCK BULKHEAD
12,300
SILTY SAND
GRAVEL - mostly pebble sand
GRAVEL - pebbly sand
BLUE CLAY - massive & SAND - highly deformed; appears swirled
DETAILED SECTIONS
SAND - stratified fine - medium
SAND - stratified medium
SAND - massive
CLASTIC DIKE - SILT & SILTY SAND
COLLUVIUM
S
ESPERANCE SAND
Qau
12,600
WHIDBEY ? FORMATION

Plate 6.11

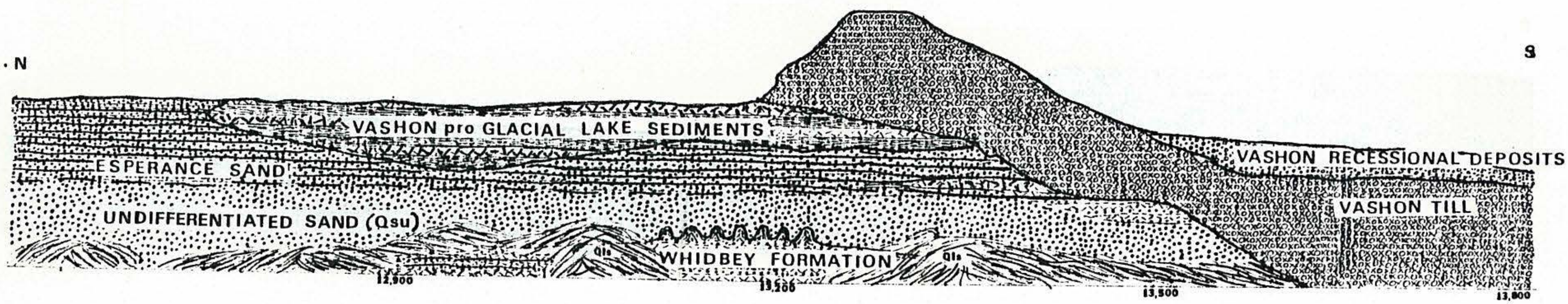

N
S
VASHON pro GLACIAL LAKE SEDIMENTS
ESPERANCE SAND
UNDIFFERENTIATED SAND (Qsu)
WHIDBEY FORMATION
VASHON RECESSIONAL DEPOSITS
VASHON TILL

Plate 6.12

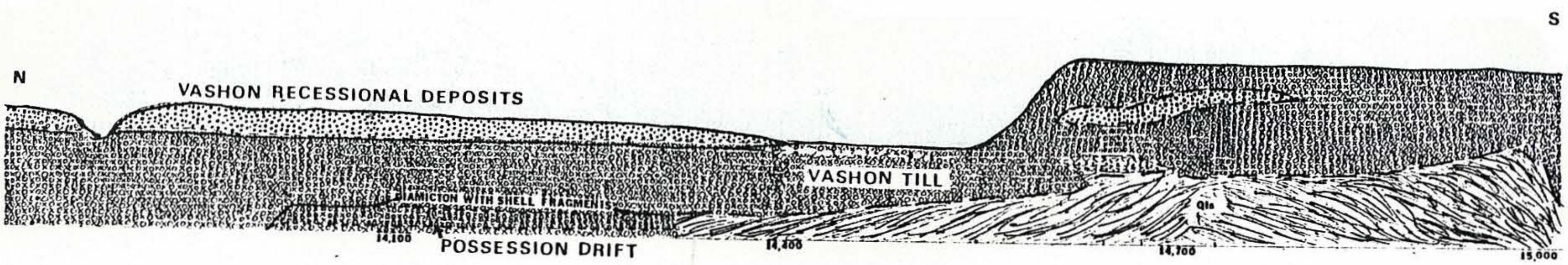

N
S
VASHON RECESSIONAL DEPOSITS
VASHON TILL
DIAMICTON WITH SHELL FRAGMENTS
POSSESSION DRIFT
Qls
14,100
14,400
14,700
15,000

Plate 6.13

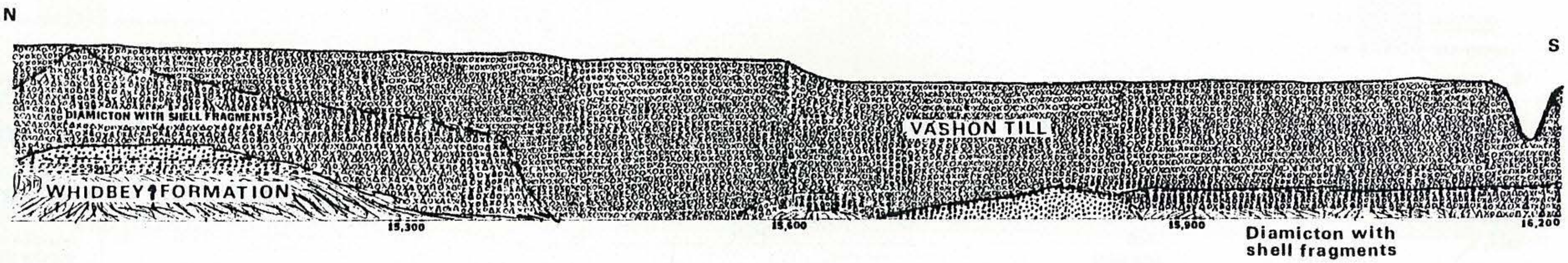

N
S
DIAMICTON WITH SHELL FRAGMENTS
VASHON TILL
WHIDBEY FORMATION
15,300
15,600
15,900
16,200
Diamicton with
shell fragments

Plate 6.14

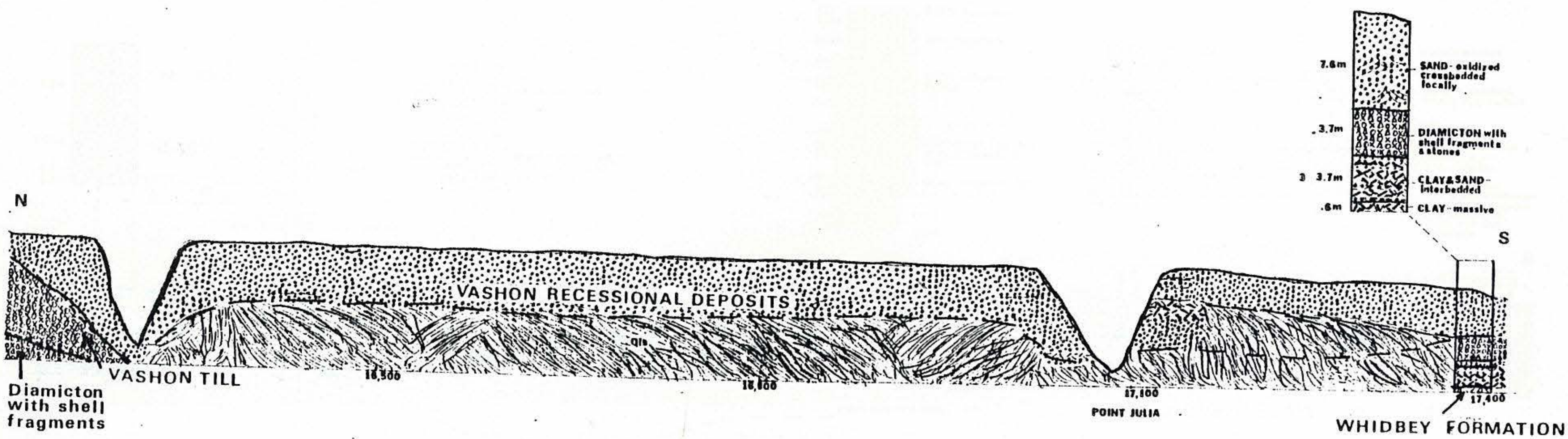
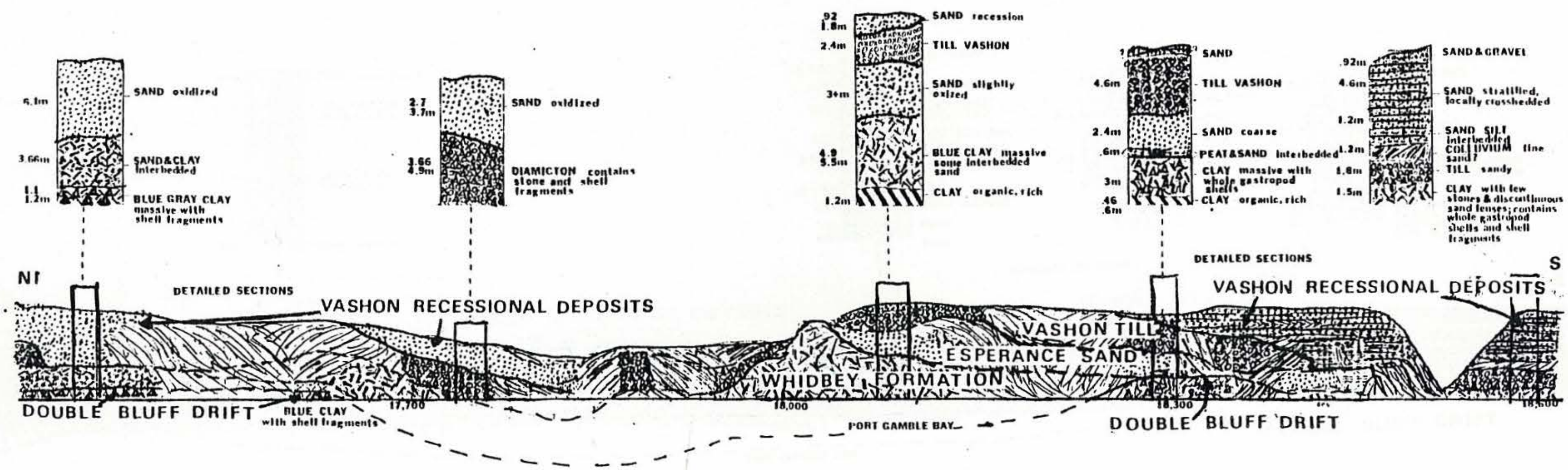
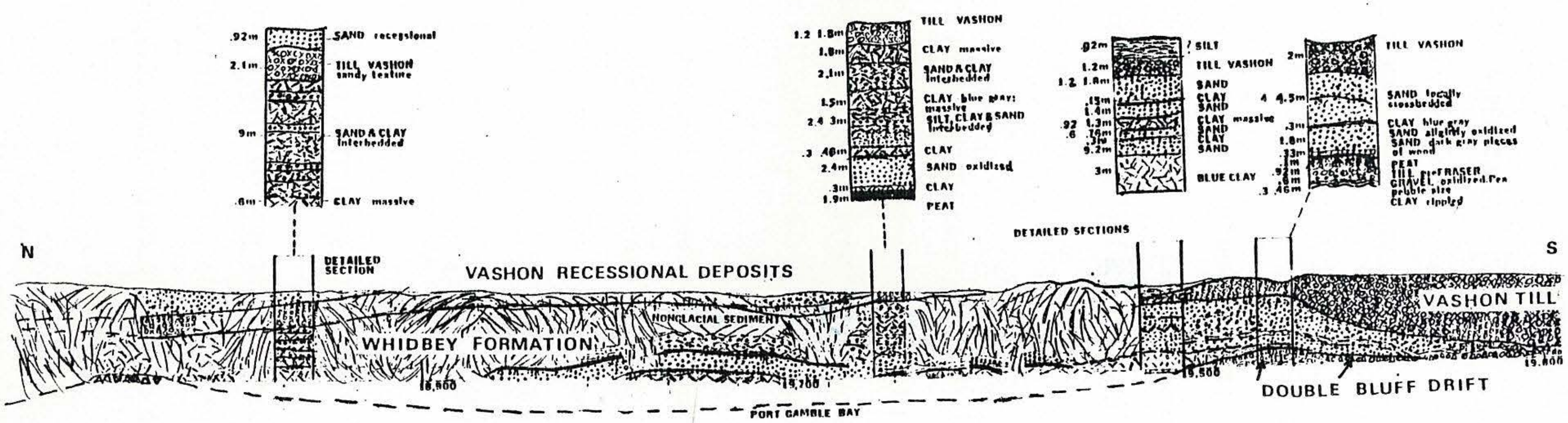

7.6m
SAND - oxidized crossbedded locally
3.7m
DIAMICTON with shell fragments & stones
3.7m
CLAY & SAND - interbedded
.6m
CLAY - massive
N
S
VASHON RECESSIONAL DEPOSITS
VASHON TILL
Diamicton with shell fragments
16,500
16,800
17,100
POINT JULIA
17,400
WHIDBEY FORMATION

Plate 6.15



6.1m
SAND oxidized
3.66m
SAND&CLAY interbedded
1.1
1.2m
BLUE GRAY CLAY massive with shell fragments
2.7
3.7m
SAND oxidized
3.66
4.9m
DIAMICTON contains stone and shell fragments
92
1.8m
SAND recession
2.4m
TILL VASHON
3+m
SAND slightly oxized
4.9
5.5m
BLUE CLAY massive some interbedded sand
1.2m
CLAY organic, rich
SAND
4.6m
TILL VASHON
2.4m
SAND coarse
.6m
PEAT&SAND interbedded
3m
CLAY massive with whole gastropod shells
.46
.6m
CLAY organic, rich
SAND & GRAVEL
.92m
4.6m
SAND stratified, locally crossbedded
1.2m
SAND SILT interbedded
1.2m
COLLUVIUM fine sand?
1.8m
TILL sandy
1.5m
CLAY with few stones & discontinuous sand lenses; contains whole gastropod shells and shell fragments
N
DETAILED SECTIONS
VASHON RECESSIONAL DEPOSITS
DETAILED SECTIONS
S
VASHON RECESSIONAL DEPOSITS
VASHON TILL
ESPERANCE SAND
WHIDBEY FORMATION
DOUBLE BLUFF DRIFT
BLUE CLAY with shell fragments
17,700
18,000
18,300
18,600
PORT GAMBLE BAY
DOUBLE BLUFF DRIFT

Plate 6.16



.92m SAND recessional
2.1m TILL VASHON sandy texture
9m SAND & CLAY interbedded
.6m CLAY massive
DETAILED SECTION
1.2 1.8m TILL VASHON
1.8m CLAY massive
2.1m SAND & CLAY interbedded
1.5m CLAY blue gray; massive
2.4 3m SILT, CLAY & SAND interbedded
.3 .46m CLAY
2.4m SAND oxidized
.3m CLAY
1.9m PEAT
.92m SILT
1.2m TILL VASHON
1.2 1.8m SAND
.15m CLAY
1.4m SAND
.92 1.3m CLAY massive
.6 .76m SAND
.3m CLAY
9.2m SAND
3m BLUE CLAY
2m TILL VASHON
4 4.5m SAND locally crossbedded
.3m CLAY blue gray
SAND slightly oxidized
1.8m SAND dark gray pieces of wood
.33m PEAT
.1m TILL pre-FRASER
.92m GRAVEL oxidized, Pea pebble size
.6m
.3 .46m CLAY rippled
DETAILED SECTIONS
N
S
VASHON RECESSIONAL DEPOSITS
VASHON TILL
NONGLACIAL SEDIMENT
WHIDBEY FORMATION
DOUBLE BLUFF DRIFT
PORT GAMBLE BAY

Plate 6.17

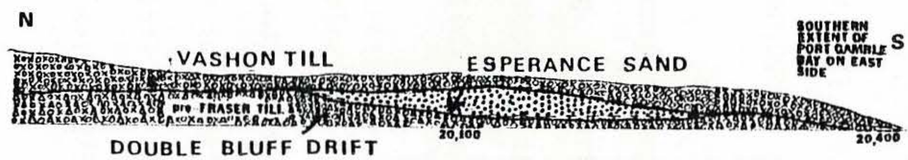

N
VASHON TILL
ESPERANCE SAND
SOUTHERN EXTENT OF PORT GAMBLE BAY ON EAST SIDE
S
pre FRASER TILL
DOUBLE BLUFF DRIFT
20,100
20,400

Plate 6.18

APPENDIX II

LAND USE FEASIBILITY

Introduction

Kitsap County has undergone rapid growth since 1974 when the Federal government selected this county as the home base for Trident nuclear submarines. The county presently (April, 1977) has a population of 126,300; projected 1995 population is 160,000 or more (Arthur D. Little Co., 1974).

This projected growth prompted the county to begin updating information necessary for land use planning. In particular, the Department of Community Development has prepared a new comprehensive plan while other projects will provide updated soils, geology and ground water information.

The geology update was prepared by geologists from the Department of Natural Resources and by the author through a grant from the Department of Housing and Urban Development. The information provided consists of surficial geology, sewage disposal feasibility, and slope stability maps. Field work for the project began in early 1975 and continued through winter and spring of 1978.

Use of Soil Survey

Most of this report deals with geology of the Kitsap Peninsula. A section has been devoted to soils, however, because both are interrelated.

Soil is the weathered uppermost layers of surface deposits, the layers on which plants anchor their roots and from which the plants derive the water and nutrients necessary for growth (Hunt, 1972). It is the result of the interaction of soil-forming processes on material deposited by geologic agents (Snyder and others, 1973). Soil maps describe the developed soil formation (for a given location) in the upper surface of previously deposited geologic materials.

Several factors determine the soil properties observed at any location; these are: (1) the physical and mineralogical composition of the parent material; (2) the climates under which the soil formed; (3) living organisms on and in the soil; (4) the topography or "lay of the land"; and (5) the length of the time the soil has been forming.

A soil survey of Kitsap County was recently completed by the U.S. Department of Agriculture, Soil Conservation Service (M_CMurphy and Ping, in press). These soil data, along with geologic and other data involved in land use planning have already been incorporated in the comprehensive plan developed for Kitsap County.

Soil data gives information on the suitability and limitations of soils for engineering applications, such as private on-site sewage disposal facilities, agriculture and urban drainage systems, foundations for buildings and structures, and water storage reservoirs and embankments. Soil data is, thus, useful as an aid in planning and preliminary design of specific development proposals and in zoning, subdivision control, and official mapping (L. J. Bartelli and others, 1966).

In Kitsap County soils and geologic information are used on a day-to-day basis by builders, developers, and health, engineering, and building departments as well as planners. All are interested in information such as: (1) suitability of soil for on-site sewage disposal; (2) depth to seasonal high water table; (3) internal soil drainage (wetness); (4) surface run-off; (5) soil suitability for foundations of roads and small buildings; (6) depth of bedrock or glacial till; and (7) other soil limitations. This information, even though provided in a survey, does not change the necessity and importance for making an on-site investigation.

Maps and surveys of an area are limited due to the large areas covered and, hence, the small scale maps used. Building or development is not necessarily ruled out in areas with soil limitations, as on-site inspections can often result in recommendations and stipulations to make the site feasible for building. The maps, whether they be geology or soils, should be used as a warning or "red flag" that an area requires further investigation prior to making any definite and final decisions as to suitability.

On-Site Sewage Disposal

Kitsap County recently adopted new regulations for on-site sewage disposal. Setback distances from drainfield to water, wells, and slopes have increased. Lot sizes are now determined by soil types and water supply; changes have also been made regarding fills and drainage.

Kitsap county now requires at least 1.2 meters of permeable soil and at least 0.9 meters vertical separation between the bottom of the disposal field and the maximum seasonal ground water elevation or impermeable layer. This latter requirement may be reduced by the health officer, but in no case can the separation be less than 0.46 meter.

Without this provision most lots in Kitsap County would be unsuitable for building since the Peninsula is covered by a mantle of impermeable glacial till which is usually within 2.5 meters of the ground surface. The average depth from ground surface to top of till is 0.6 to 1.0 meter. Fill material may be used only as cover over the drainfield, up to a maximum of 0.46 meter, and no part of the drainfield may be installed in the fill. This means that if a lot has a minimum depth to an impervious layer of 0.76 meter, the draintile may be permitted to be installed high in the upper portion of the original soil and then covered with the 0.46 meter of additional fill to obtain the required 1.2 meters.

Other than adequate soil depth, the most significant problem is perched ground water overlying the impervious layer (Figure 63). In areas of adequate slope and soil depth, interceptor ditches may be dug upslope from the drainfield and drainage can be diverted away from the area. Lots in small basins or on very flat ground, however, are very

Figure 63. One of the major problems in Kitsap County for on-site sewage disposal is perched groundwater above an impervious soil.

difficult or impossible to drain, often making the lot unbuildable. The health officer may allow fill on some of these lots if it is justified, and meets specifications required by the Bremerton-Kitsap County Health Department.

Downward percolating sewage will move laterally along the interface between overlying soil and an impervious layer; thus, when drainfields are installed above breaks in slope, the sewage will often surface where the ground flattens out. The probability of this occurring increases where distance between breaks in slope is fairly small. The new regulations take this into account by requiring drainfields to be set back from any slope in excess of 30 percent. The setback distance required is 4.6 meters plus the height of the bank or slope. For example, if a bank is 20 meters from the toe to top, the setback distance would be 4.6 meters plus 20 meters or a total of 24.6 meters. This set back offers adequate protection from sewage effluent seeping out at the bank or surfacing downslope. Where sewage disposal systems are installed on slopes up to 30 percent that exist over an impervious layer, interceptor drains should be installed. By diverting all other ground and surface drainage, as well as roof and footing drains away from the field area, the sewage can distribute itself over the entire drainfield area and its chance of surfacing is reduced.

Present regulations use percolation rate, soil type, and water supply to determine a lot size. Acceptable percolation rates for various soil classes, determined by personnel at the Department of Social and Health Services, Water Supply and Waste Division, are lower than those used by the Soil Conservation Service. For example, according to state regulations any percolation rate over 30 minutes/2.54 centimeters is unacceptable; whereas the soil conservation service designates as unacceptable any percolation rate over 45 minutes/2.54 centimeters. Table 8 relates minimum lot size to soil type and water supply. By using the table, a soil consisting of fine sand with some silt which has a percolation rate of 5 - 9 minutes/2.54 centimeters is classed as a soil type 3. Under public water supply, the type 3 soil requires lot size of 15,000 square feet. Where percolation rates are slower, larger drainfields are necessary and, thus larger lot sizes are required.

Rapid percolation rates do not always indicate satisfactory soils. Soils with percolation rates of one minute or less/2.54 centimeters are

WAC 248-96-090 MINIMUM LOT SIZES FOR SUBDIVISIONS. One of the following methods shall be used for determining lot sizes when on-site sewage disposal is used

METHOD (1) TABLE 8 MINIMUM LOT SIZES

	SOIL TYPE					
WATER SUPPLY	1	2	3	4	5	6
Public	1* acre	12,500 sq.ft.	15,000 sq.ft.	18,000 sq.ft.	20,000 sq.ft.	----
Individual-Each Lot	2* acres	1 acre	1 acre	1 acre	2 acres	----

Soil Type	Drainage	Percolation Rate**	General Soil Classification
1	Excessive	Less than 1 minute/inch	Gravel, coarse sand, cobbles
2	Good	1 - 4 minutes/inch	Sandy soil, some loam, some gravel
3	Fair	5- 9 minutes/inch	Finer sand and/or silt, few gravels
4	Poor	10 - 19 minutes/ inch	Mostly silt or clay, some sand and shot clay
5	Marginal	20 - 29 minutes/ inch	Silt or clay
6	Unacceptable	Over 30 minutes/ inch	Gumbo, rock, hardpan, clay pan

*Lot sizes for soil type 1 can be reduced by the health officer if engineering justification can be provided that shows significant adverse effects on ground water quality will not occur; however, in no case shall the reduced size be less than that for soil type 2.

Table 8. Soil type and minimum lot size in Kitsap County. Washington State Department of Social and Health Services, 1974, Rules and Regulations of the State Board of Health for on-site Sewage Disposal Systems, p. 6.

considered excessively drained and require larger lots to insure the effluent is adequately treated. With public water supply, lots with excessive drainage must be one acre or larger; lots with individual wells must be at least two acres in order to provide greater distance between wells and drainfield. Coarse sand and gravel containing only a very small percentage of fines, typical of some recessional outwash deposits, is an example of material with excessive drainage.

New set-back requirements from septic tank and drainfields to wells

WAC 248-96-100 LOCATION. (1) The minimum distance for location of the various component parts of the on-site sewage disposal system is measured horizontally and shall comply with Table II.

TABLE 9. MINIMUM DISTANCE IN FEET

Component	Well or Suction Line (a)	Water Supply Line Under Pressure	Surface Water (a)(b)(c)	Building	Property Line	Open Ditches or Cuts Down Hill Side
Building sewer	50	10	10	--	--	--
Septic tank	50	10	50	5	5	--
Tile field or dry well	100	10	100	10	10	15 + Height of cut or bank

(a) In soil types that are classified as having excessive drainage characteristics in accordance with WAC 248-96-090, the distance from any water supply or surface water may be increased by the health officer.

(b) Setbacks from surface waters shall be measured from mean high water.

(c) A reduced separation can be allowed between the tile field or dry well and the well or surface water by the health officer if it can be demonstrated that the reduction will not have an adverse effect. However, in no case shall the separation be less than 75 feet.

(2) The area to be used for sewage disposal shall be selected and maintained so that it is free from encroachment by buildings and other structures. The area shall not be subject to vehicular traffic and shall not be covered with an impervious surface.

(3) The on-site sewage disposal system shall not be located in an area where surface water will accumulate. Provisions shall be made to minimize flow or accumulation of surface water over the area.

(4) No part of an on-site sewage disposal system shall be constructed in a state flood control zone, before a flood control zone permit is obtained from the department of ecology. Such permits are issued under the provisions of Ch. 86.16 RCW and Ch. 508.60 WAC.

Table 9. Set-back requirements for Kitsap County. Washington State Department of Social and Health Services, 1974, Rules and Regulations of the State Board of Health for on-site Sewage Disposal Systems, p. 8.

surface water, property lines, buildings, ditches, and banks are shown in Table 9; some are substantial increases over old requirements. Distance from drainfields to wells or surface water has increased from 15 meters to 30 meters and, as previously mentioned, set-backs from banks in excess of 30 percent are now required.

Old meltwater channels forming valleys between till-mantled uplands are frequently sites of rural development, with Big Valley, north of Poulsbo, and Olalla Valley, south of Long Lake, typical examples. Glacial till usually underlies these valleys at depth of 0.6 to 2 meters. Drainage is usually very poor and results in the development of Black organic soils (Figure 64). After heavy rains water usually stands on the surface. Throughout the year the water table is within 0.6 meter of the ground surface. It is generally impossible to drain these areas, and even if it were possible, soil permeability is too

Figure 64. Valleys between till-mantled uplands are often underlain by till and are poorly drained.

slow for adequate functioning of on-site sewage disposal. Fill cannot be used because of the possibility of contaminating surface waters or of erosion of the fill. Thus the bottom areas of these valleys are poor building sites.

Many building lots in Kitsap County are in areas with shallow soils, drainage problems, or slow percolation rates. These problems are generally solved by proper design. Slow percolation rates are overcome by installing additional draintile to spread the effluent over a larger area. Shallow soils, as long as they meet minimum requirements, can have additional fill placed on them up to a maximum of 0.46 meter. Lastly, interceptor ditches can be installed to alleviate drainage problems. If any one of these problems cannot be adequately solved, another site for the drainfield must be found. Kitsap County has between 10 to 20 percent drainfield failures per year. For each failure there is at least one or more reasons for that specific failure. The following is a list of some of the common reasons why drainfield failures occur:

1. Poorly drained soils. Percolation tests done during very dry conditions do not indicate any drainage problem when there actually is a problem during wet periods. Therefore, drainfields may function well in dry weather but fail in wet weather.
2. Inadequate percolations tests. Percolation tests may be inadequate when the gound is not saturated properly prior to determining the percolation rate. Frequently, water is poured in the hole and rates are read without allowing

proper saturation. Therefore, drainfields are underdesigned for the soil and fail.

3. Shallow soils. Shallow soils over glacial till, bedrock, clay pan, or some other type of impermeable layer do not allow for vertical absorption of sewage effluent and often result in failure.
4. Slopes. Drainfields on slopes between 15 and 30 percent that are not designed properly or have an impermeable layer below allow sewage to seep out downslope.
5. Flooding. installing drainfields in areas subject to periodic flooding results in failure.
6. Overcrowding in a residence. The drainfield for a three-bedroom house is designed according to the number of bedrooms and the soil; a family of six living in the house, (as opposed to a family of three or four) may overload the system and result in failure.
7. Use of garbage disposal unit. Garbage disposal units cause drainfields to fail sooner because of excess grease and solids.
8. Sewage saturation of soils. After many years of use, sewage eventually clogs the pores in the soil and effluent cannot spread laterally or move vertically downward.
9. Improper maintenance of the disposal system. Not having the tank pumped periodically allows solids to enter the drainfield. Homeowners also overburden the system by heavy water use within a single day, thereby not allowing the drainfield sufficient time to absorb the sewage.

10. Driving on the drainfield. Placement of driveways and parking areas over drainfields often results in draintile being crushed and soils compacted.

Most drainfield failures can be prevented through proper maintenance and proper site selection.

For any potential building site the following things must be assessed and evaluated:

1. Soil permeability. The soils must be thoroughly saturated prior to making readings of the percolation rate. Percolation rates must be less than 30 minutes/2.54 centimeters.
2. Groundwater level. The highest groundwater level during the wettest season should be at least 1.2 meters below the tile. Although this distance can be reduced to 0.45 meter in health districts with designer programs, the distance should be kept as far as possible. Clues to high water tables are gleyed soils and presence of water-loving vegetation such as sedges, willows, cedars, and spruce (Dunne and leopold, 1978, p. 181).
3. Soil depth. Bedrock or impervious layers should be 1.2 meters below the tile. This is not always possible, but at least 0.76 meter of original soil overlying the impervious layer is required. The maximum distance between the bottom of the tile and the impervious layer should be maintained.
4. Slope. If possible, design on slopes less than 15 percent. If slopes exceed 15 percent, the distance to any impermeable layer should be sufficient to prevent seepage.

5. Water bodies and wells. No wells or water bodies are permitted within 30 meters of the drainfield.
6. Floodplains. Avoid placing drainfields in areas subject to periodic flooding. Investigate suspect areas by contacting appropriate agencies such as the local soil conservation office or health department.
7. Differences in soil types. Areas where soil types change dramatically may not be feasible for on-site sewage, especially if the soils differ in their absorptive capacity.
8. High bank setback. If steep banks or slopes in excess of 30 percent exist, a setback from the upper edge of the bank to a drainfield is required.

If all of these items are observed carefully, problems with septic tank and drainfield should be minimized and the system should function properly for a long period of time.

For more specific information on drainfield failures and proper design for on-site systems, the reader is referred to the Manual of Septic Tank Practice.[1]

---

[1]Manual of Septic Tank Practice, U. S. Department of Health, Education, and Welfare, 1972. Public Health Service, Publication no. 256, p. 92.

APPENDIX III

SLOPE STABILITY

Slope staility is of considerable importance to land use planning in Kitsap County. The county contains 365 kilometers of shoreline, of which 174 kilometers (47.8%) is high bank while 96 kilometers (27.2%) is low bank (Kitsap County Department of Community Devlopment, 1976). Recent slope stability maps (Kitsap County Department of Community Development, 1976) indicate that most of these shorelines are either undergoing active sliding (marked by recent slides and unstable slopes), or have been the site of landslides in the past. Most of the remaining slopes have the potential for becoming unstable. Thus, with development at a peak in the county, and with waterfront property in high demand, it is essential that areas with slope hazards be brought to the attention of land use planners, builders, and homeowners.

In Kitsap County most naturally unstable slopes lie either along sea cliffs or along steeper valley sides. This instability depends on the following factors:

1. Slope. Steep slopes are generally less stable than gentle slopes. If materials and degree of saturation are constant, as slope angle increases slopes become progressively less stable. Because other variables are involved, however, slope alone cannot be used as a stability criterion.
2. Composition and structure. The composition and geologic structure (i.e., bedding, jointing) of the materials that make up a slope are important in determining its stability.

Bedding planes or joint planes in clay, till, or rock are surfaces or reduced strength; where these surfaces dip out of (or run parallel to) a slope, they form surfaces along which sliding can readily occur. Water moving downslope along joints or bedding reduces material strength by lubricating the joint or bedding planes and by increasing internal pore pressures. In winter, water may freeze along such surfaces, causing outward expansion. When the ice thaws, the overlying material (especially if clay) tends to slide.

Unconsolidated materials composed of sand or gravel will, where undercut or oversteepened, slide until they reach their particular angle of repose. Materials containing more silt and clay, such as till or silty sand, possess cohesion and may stand near-vertical for relatively long periods of time. Erosion of these slopes takes place mostly by slow spalling related to freezing and thawing or wetting and drying or by undercutting (spring-sapping) where ground water emerges from the free face. Clays and silts tend to be especially unstable, due to low strength, poor drainage (and thus high pore-pressures), and susceptibility to disruption by swelling and shrinking on wetting and drying. Clay overlying a compact sand often will fail due to the sand liquifying, causing disruption of the overlying clay. This has occurred at Apple Cove Point, north of Kingston (Figure 65) where damage to several cabins and property resulted. Generally when a more permeable soil overlies a more dense and less permeable soil, a perched water

Figure 65. Softer clay overlying dense,sand will, upon saturation, flow over the denser sand. Apple Cove Point, north of Kingston in sec. 24, T. 27 N., R. 2 E.

Figure 66. Large landslide deposit near Warrenville, north of Seabeck. Toe of slide with new growth of trees seen in foreground. Base of bluff consists of clay. Sec. 14, T. 25 N., R. 1 W.

water table occurs above the interface, separating the two units and forming a saturated zone. High pore pressures in this saturated zone reduce the strength of the materials and may result in slumping or mudflow.

The opposite relationship may also occur. In such a case, weaker material underlies a more competent unit (such as till overlying clay or compact sand overlying clay). The lower unit will often erode faster due to wave erosion, spring sapping, or man modifying natural conditions, and undercut the overlying unit; this will eventually cause collapse (Figure 66). Such slope failure has occurred frequently along much of the shoreline in the county.

3. Water. The presence of water available to infiltrate the ground plays an important role in slope stability. In Kitsap County large quantities of rain generally fall from late fall until early spring. Because of low evapotransporation rates, much of this water either infiltrates the ground and eventually recharges the aquifer or ends up as runoff which eventually returns into Puget Sound, Hood Canal, or Admiralty Inlet. Water infiltrating the ground forms zones of local saturation during the wet period; high pore pressures in these saturated zones greatly reduce the strength of the materials involved. If the downslope component of the weight of the slope exceeds this saturated strength, a landslide will occur (M. Smith, 1977, oral communication). Most landslides in Kitsap County occur during late winter and spring when ground water levels are near their highest levels.

4. Wave Erosion. During winter storms, waves undercut and steepen shoreline slopes. Because of the large percentage of high-bank shoreline in Kitsap County, wave undercutting is particularly important as such action causes slope instability. Older slide debris acts as protection from further sliding as long as it remains in place at the toe of the old slide. Active wave erosion eventually removes this material, however, and once again attacks the slope until another slide occurs.

5. Modification of Natural Conditions. Human activities that tend to destabilize slopes are:

   a. Excavations that steepen slopes reduce stability and accelerate movement on the slope. They may also alter the natural drainage and destabilize the slope.

   b. Excavations on ground that is nearly level such as for highways or buildings may enable water to seep into colluvial ground and activate sliding on slopes below (Hunt, 1972, p. 307).

   c. In many hilly areas construction of residences and streets increases the landslide hazard by adding to the load on potential slide blocks and by improperly modifying the natural drainage (Hunt, 1972, p. 308) (Figure 67 and 68, Figure 69 p. 155).

   d. Residential construction with septic tank and drainfield plus roof and footing drains increases water infiltrating the ground, thus reducing slope stability (Figures 67 and 68).

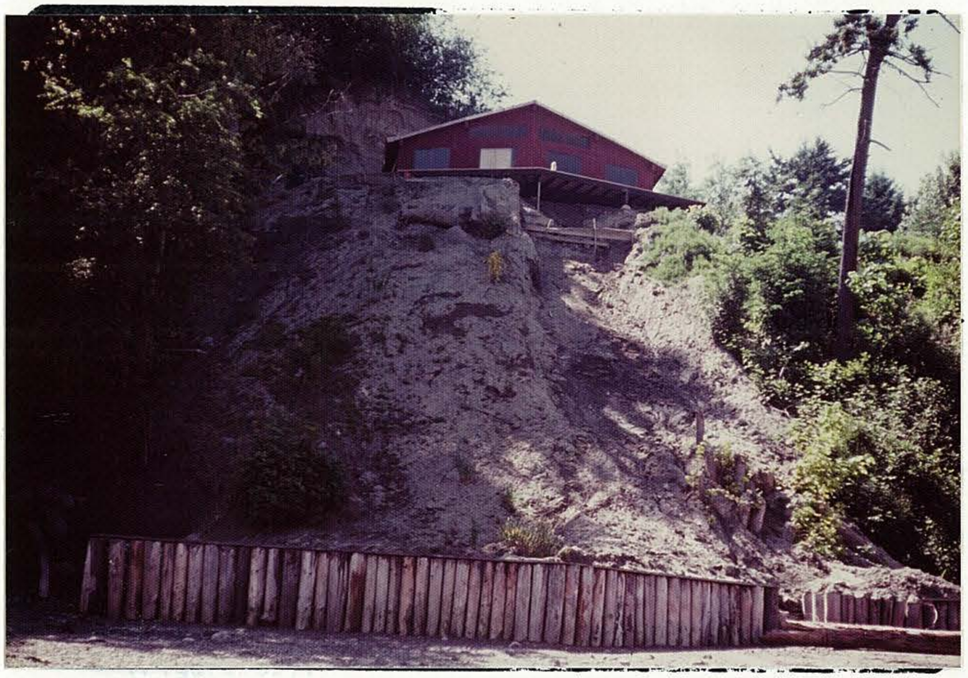


Figure 67. Home built directly on recent slide; debris provides a potentially dangerous situation. View Park, north of Fragaria in sec. 14, T. 23 N., N. 2 E.

Figure 68. Recent slide caused in part by improper drainage and removal of vegetation by home built in upper part of bluff, north of Frenchmen Cove in sec. 34, T. 25 N., R. 2 W.

e. Emplacement of artificial fill modifies the load on a slope causing a permeability difference which results in perching and sliding of the fill.

f. Clear cutting slopes reduces evapotranspirative losses from the soil and hence increase the amount of water in the soil. In addition, root decay reduces soil strength (Bishop and Stevens, 1964).

g. Removal of slide debris at the toe of a slope will enable wave erosion to directly attack and undercut the slope.

h. Undercutting the base of a slope can cause collapse (Figure 69).

i. Building on old landslides and modifying them by excavation or changes in ground water increases instability.

Figure 69. Undercutting of lower slope in Esperance sand to increase area has resulted in slope failure, south of the Creosote Plant, Bainbridge Island in sec. 36, T. 25 N., R. 2 E.

6. Seismic Activity. Earthquakes cause sudden jarring and ground vibration which may trigger landslides.

In some instances the factors which cause slope instability can be altered to make an unstable area safe. Common methods used to stabilize slopes are: (1) placing retaining walls or bulkheads at the base of slopes, which is effective only on relatively small slide areas; (2) using piles; (3) draining the slide and slide plane to reduce saturation; and (4) grouting. As long as the modification(s) used is maintained, the slope should remain stable. In any case, thorough geologic and engineering investigations are imperative if naturally unstable slopes are to be modified or developed safely.

Setback requirements, which are to be determined by on-site investigation, also have to be implemented for unstable areas. Severe slope conditions will require larger setbacks for building than slopes with only minor slope problems. Exact setback requirements have not been set for Kitsap County. The scale of the slope stability map and procedures used in mapping at such a scale limit the use of the map and is another reason why on-site investigations must take place. At such times unstable boundaries can be determined and the setback enforced. The map should only be used as an indication that a given area requires more investigation prior to issuance of building permits.

Map Units

The slope stability categories used by the author in the accompanying map (plate 9, map pocket) are described below. These categories are basically the same as those used by the Department of Natural Resources in their shoreline inventory; I have added one new subcategory.

1. Stable. (Map symbol-S). Slopes are generally less than 15 percent except in local areas of low water table or competent bedrock. It includes rolling uplands and lowlands underlain by very stable material such as weathered till and deposits such as peat, which although inherently weak, have no significant slope.
2. Intermediate$_1$. (Map symbol-I). Slopes are generally between 15 and 30 percent. This category includes slopes without known failures in sand, gravel, till, and thin soil over bedrock.
3. Intermediate$_2$. (Map symbol-I_0). Slopes are steeper than 30 percent. This includes slopes without known failures in sand and gravel, till, and thin soil over bedrock. In the vicinity of Green and Gold Mountains, talus from rock falls is found at the base of slopes in this category. This subcategory was used because slopes in excess of 30 percent cannot be used for placing of on-site sewage disposal systems. (Washington State Department of Social and Health Services, 1974, Rules and Regulations of the State Board of Health for On-Site Sewage Disposal Systems WAC 248-96.
4. Unstable. (Map symbol-U). Slopes considered unstable due to geologic, ground water, slope, or erosional factors. This category includes areas of landslides and talus too small or obscure to be individually mapped. The symbol (Urs) is used for recent or historically active landslides, and the map

symbol (Uos) is used for old, post-glacial but prehistoric landslides.

5. <u>Modified Slopes</u>. (Map symbol-M). Slopes highly modified by man. This includes areas of significant excavation and filling. Slope response to a combination of natural processes and man's activities are unpredictable except by detailed on-site investigation.

Table 10

FEASIBILITY OF SOILS FOR ON-SITE SEWAGE DISPOSAL

Soil Name	Geologic Description	Soil Description	Permeability	On-Site Sewage Limitations
Alderwood very gravelly, sandy loam	Vashon till found on undulating to steep uplands	Sandy gravel loam with cemented substratum at 0.5 to 1 m. Perched water table generally found on slopes <8%. Moderately well drained.	Moderate to poor	Septic tank and drainfield sewage lagoons and sanitary landfills are all rated severe due to cemented pan and wetness. Water moves on top of substratum in winter and oftern presents problems with drainage on slopes <15%.
Neilton gravelly loamy sand	Soils formed on terraces in stratified very gravelly outwash deposits	Dark brown to yellowish brown, very gravelly loamy sand to a depth of 0.46 m. Gray-brown gravelly sand substratum to 1.5 m	Good to excessive	Slight to moderate. On slopes >15% limitations become severe due to excessive drainage.
Indianola loamy sand	Sandy, outwash of recessional or advance origin associated with eskers, kames, and deltaic deposits	Brown to dark brown. Light olive brown loamy sand surface layer to 0.76 m in depth. Underlain by 1.5 m of olive sand substratum	Good to excessive	Slight to moderate on slopes ≤15%, becoming severe on slopes >15%.

Soil Name	Geologic Description	Soil Description	Permeability	On-Site Sewage Limitations
Kitsap Silt Loam	Lacustrine deposits both glacial and nonglacial. Found on upland benches, terraces, very steep breaks in slope	Very dark gray brown and dark brown silt loam surface with gray brown subsoil and olive brown silt loam and clay loam substratum	Poor	Severe
Indianola Kitsap Complex	Nonglacial interbedded fine sand and silt. Overlies Esperance sand	Sand and silt of varying thickness	Variable; good in sand to poor in clay	Severe due to steep slopes and clays
Norma fine sand loam	Recent alluvial soils formed along upland drainages or in basins on the glacial till plain	Typically black sandy surface. Major use is agriculture	Poor. Subject to frequent flooding	Severe. Impossible to drain due to very gentle slopes.
Shalkar muck	Soils formed in deposits of sludge peat and alluvium in stream valleys and on rolling glaciated uplands	Poorly drained organic soils. Very dark brown muck surface layer overlies stratified organic matter and mineral layers and a dark gray loamy sand	Poor	Severe due to high water table and flooding.

Soil Name	Geologic Description	Soil Description.	Permeability	On-Site Sewage Limitations
Kapowsin gravelly loam	Vashon till	Dark brown and dark yellowish brown gravelly loam surface and subsoil	Moderate	Severe due to high water table and restrictive till substratum
M^{c}Kenna gravelly loam	Glacial till in depressions and sloping drainage ways on glacial uplands	Poorly drained with perched water table. Soil reddish brown - gravelly silt loam or dark yellowish brown with olive brown subsoil and thick cemented till substratum	Poor	Severe due to high water table, frequent flooding and slow percolation.
Sinclair very gravelly sandy loam	Forms on Vashon till on slopes 2 to 15%. These soils occupy fairly flat to gentle slopes at the head or side of drainage ways where groundwater movement is slow	Very gravelly sandy loam 0.6 to 1.6 m thick; below which is cemented till	Variable	Severe due to perched water table resting on till

Soil Name	Geologic Description	Soil Description	Permeability	On-Site Sewage Limitations
Poulsbo gravelly loam	Formed on sandy, glacial till plains	Beneath a thin organic mat, topsoil is dark gray-brown, very gravelly sandy loam. Subsoil is dark brown gravelly sand loam and substratum weakly to moderately cemented, light olive brown and olive gravelly sandy loam	Variable	Severe due to high water table
Ragnar fine sandy loam	Recessional and advance sandy ice contact deposits	Very dark gray-brown, dark yellowish brown and yellow brown, fine sandy layer and subsoil 0.68 m thick. Olive brown loamy sand substratum to 1.5 m	Good	Slight to severe, depending on slope. Slight on slopes < 8%, severe on slopes > 15%.
Tacoma silt loam	Alluvial deposits and organic material on deltas adjacent to tidelands	Dark brown silt loam surface layer, dark gray-brown silt loam subsoil, and a stratified silt loam and clay substratum	Poor	Severe due to high water table and flooding. Usually impossible to drain

Soil Name	Geologic Description	Soil Description	Permeability	On-Site Sewage Limitations
Bellingham series	Alluvial soils formed on nearly level glacial uplands	Black silt loam, clay loam, or silty clay loam topsoil. Gray or dark gray silty clay and clay subsoil	Poor	Severe due to wetness, floods, and slow percolation
Dupont soils	Organic-rich sediments (Q_{ps}) formed in depressions on uplands	Consist of organic material down to 1.8 m	Poor	Severe due to floods, high water table, and slow percolation
Mukilteo soils	Formed on organic materials found in depressions upland terraces, and stream valleys	Dark yellow brown and dark reddish brown muck surface layer 0.15 m or more thick	Poor	Severe due to poor drainage, high water table, and flooding
Semiahmoo (Q_{ps}) muck	Organic-rich sediments formed in depressions on floodplains	Black, reddish brown and very dark brown muck to 1.5 m	Poor	Severe due to high water table from November through May, flooding, and poor drainage

Soil Name	Geologic Description	Soil Description	Permeability	On-Site Sewage Limitations
Grove	Glacial outwash on terraces and terrace breaks in slope; gravelly ice contact deposits	Thin mat of organic material overlying dark reddish brown very gravelly loamy sand, upper subsoil 0.3 m thick. Lower subsoil reddish brown, very gravelly coarse sand 0.4 m thick. Substratum very dark gray-brown, gravelly coarse sand to 1.5m	Excessively drained	Slight on slopes <8% and severe on slopes >15%
Harstine gravelly sandy loam	Formed in sandy glacial till on slightly undulating to steep uplands	Dark yellowish brown and dark brown gravelly sandy loam surface layer; subsoil 0.9 m thick. Cemented till substratum to 1.5 m or more. Depth to till varies 0.06 to 1 m	Moderate	Severe due to wetness and glacial till
Dystic Xerorthents	Mixed glacial outwash and till on slopes 45 to 90%		Variable but mostly excessive due to slope	Severe due to steepness of slope

Soil Name	Geologic Description	Soil Description	Permeability	On-Site Sewage Limitations
Urban land-Alderwood complex	Areas mapped as artificial fill	Occur on slopes of 0 to 8% and are usually found in highly developed areas along shorelines as extensions of land areas into marine waters	Variable	Slight to severe
Beaches	Medium to coarse sand with some gravels deposited on spits and in protected bays and shoreline where wave action deposits rather than erodes		Good to excessive	Severe due to excessive drainage erosion by winter storms, and extreme high tides
Kelches very gravelly sandy loam	Weathered basic igneous rock	Surface layer dark reddish brown, very gravelly silt loam varying in thickness; bedrock at 0.3 to 0.5 m depth	Variable	Severe due to steep slopes and shallow depth to underlying bedrock

Soil Name	Geologic Description	Soil Description	Permeability	On-Site Sewage Limitations
Schneider very gravelly loam	Weathered colluvial basalt on steep to very steep uplands	Dark reddish brown, very gravelly silt loam surface 0.2 m thick. Underlying dark brown and dark yellow brown, very gravelly to extremely gravelly silt loam 1.3 m overlying basalt	Good to moderate	Severe due to steep slopes
Cathcart	Formed in glacial till and residium weathered from siltstone and sandstone	Very dark gray-brown loam surface layer 0.2 m thick. Subsoil dark brown and yellowish brown loam, fine sand loam 0.68 m	Poor	Severe.

Table 11

EXPLANATION OF SOIL RATINGS
(Based on Wash. State Dept. of Social and Health Services, 1974, Rules and Regulations of the State Board of Health for On-Site Sewage Disposal Systems, p. 6 and 8).

	Slight	Moderate	Severe	Excessive	Good	Poor
Permeability perc rate in minutes per 2.54 centimeters		>9 min/2.54cm and <19 min/2.54cm		<1 min/2.54cm	>1 min/2.54cm and <9 min/2.54cm	>20min/2.54cm. Unacceptable at >30 min/2.54cm
Soil depth to impervious lense	>1.6m	1.6m- 1m	<1m			
Groundwater	>1.6m	<1.6m and >1m	<1m			
Slope %	<15%	>15% but <30%	>30%			

APPENDIX V

Table 12

UNDATED PEAT AND SHELL SAMPLE LOCATIONS IN KITSAP COUNTY

Location	Stratigraphic Unit	Description
Foulweather Bluff NE¼ NE¼, sec. 12, T. 28 N., R. 2 E. Plate 7.6 between two antennae	Qw	Two peat units exposed at base of sea cliff. Lower peat lies on beach just below high tide and overlies a till. Upper peat is 0.8 to 1.3m above lower unit; it is interbedded by sand and clay, and overlain by finely oxidized gravel. Both peats are discontinuous.
Foulweather Bluff Approximately 300m west of above location	Qdb	Pebbly clay diamicton containing abundant whole shell and shell fragments.
Twin Spits SE¼ SE¼, sec. 12, T. 28 N., R. 1 E. 1,000m south of Foulweather Bluff Plate 7.7	Qdb	Diamicton containing whole shell and shell fragments. Unit is 2.7m thick and is underlain by 2.4m of fine sand while overlain by 4.5m of sand and gravel.
SE of Twin Spits NE¼ NE¼, sec. 13, T. 28 N., R. 1 E. Just east of 8,100m mark Plate 7.8	Qk	Two peat units exposed at base of bluff. Lower 0.3m peat is interfingered in blue clay. Overlying peat is 0.9m of blue clay and a 0.3m organic rich silty material.
N of Sheltered Bay NW¼ SE¼ of SE¼, sec.18, T. 28 N., R. 2 E. Near 10,200m mark Plate 7.10	Qp or Qdb	Pebbly clay diamicton containing shell fragments exposed above beach overlain by lense of sand and gravel.
S of Coon Bay (2km) NE¼ SW¼, sec. 18, T. 28 N., R 2 E. Near 14,000m mark Plate 7.13	Qp or Qdb	Pebbly clay diamicton containing shell fragments. Unit overlain by Vashon till and underlain by pre-Vashon till. Unit exposed approximately 2m above beach.

S of Coon Bay 15,000m to 16,300m mark Plates 7.14 and 7.5	Qp or Qdb	Same as above
S of Little Boston- Eastside Port Gamble Bay NW¼ NE¼, sec. 8, T. 27 N., R. 2 E. Between 17,400m to 18,700m mark Plates 7.15 and 7.16	Qdb	Number of deposits containing whole shell and/or shell fragments. Units involved range from blue-gray clay with shell fragments to peaty clay and clay containing whole gastropod shell and diamicton containing shell fragments.
Eastside Port Gamble Bay SE¼ SE¼, sec. 8, T. 27 N., R. 2 E. 19,000m to 19,500m mark Plate 7.17	Qw	Peat unit found right at sea level to several meters above. Peat varies in thickness with maximum thickness 1m.
Skunk Bay NE¼, sec. 18, T. 28 N., R. 2 E. 3,300m to 3,600 m mark Plate 7.4	Qp or Qdb	Pebbly diamicton containing shell fragments and some wood. Thought by Sceva (1957) and Garling and others (1965) to be glaciomarine. Diamicton overlain by Vashon till.
Skunk Bay E of above exposure along beach bluff from 2,300m to 1,800 m mark Plate 7.3	Qp or Qdb	Pebbly diamicton containing abundant number of shell fragments exposed 6 to 12m above beach.
N of Kingston Ferry NE¼ SW¼, sec. 25, T. 27 N., R. 2 E. Near 220m mark Plate 6.1	Qk	15cm peat dipping N 20° E. Overlies interbedded clay and sand.
NW end of Apple Cove Point SE¼ NE¼, sec. 24, T. 27 N., R. 2 E. Measured section Plate 6.3	Qk or Qw	Woody peat exposed directly on beach.
NW of Apple Cove Point NW¼ SE¼, sec. 14, T. 27 N., R. 2 E. Near 4,500m mark Plate 6.4	Qdb	Clay with whole shell and shell fragments exposed just above beach.
NW of Apple Cove Point (above) Plate 6.4	Qw	Piece of wood found 3m above beach in slighly oxidized sand.

S of Point-No-Point 28/2E-22 and 27 Near the 12,350 m mark Measured section Plate 6.10	Qk	Pieces of wood and charcoal exposed in lower sand unit.
Bluff facing to the NE directly opposite Kingston NE½ NE¼ sec. 35	Qk-upper Qw-lower	Several thick peat lenses are exposed above beach. One peat is approximately 1 m thick, the other peat is 1.5 to 1.8 m of interbedded lenses of peat and sand. Exposure is 2.5 m above beach and overlain by pebbly gravel lens .
Indianola--1.2km east of pier SW¼ NW¼ 26/2E-14 Plate 5	Qw	0.3 to 0.36 m of peat exposed approximately 2 to 2.5 m above beach. Overlain by interbedded clay, sand, and gravel. Underlain by inter-fingering sand and clay 1.2 m thick with 1 m of sand and clay above. Peat and fine grained deposit are found east of the above location near steep bluff. Chunks of the peat found on beach but could not find exposures in bluff.
S of Faye Bainbridge State Park--1.6 km SW¼ NW¼ 25/2E-2 Figure 31	Qw	Peat and clay interbedded within thick oxidized gravel unit.
S of Fay Bainbridge State Park--approximately .5 km S of the above location NE¼ SE¼ sec. 2	Qw	Peat found lying directly on beach. Overlying peat is at least 2.5 m of oxidized dense gravel and sand, possibly Whidbey or Double Bluff in age.
S side of Blakely Harbor, Bainbridge Island NW¼ NW¼ 24/2E-12	Qns	Numerous pieces of peat found washed up on beach. Believe exposure of peat is located within low tide.
N of Fletcher Bay, Bainbridge Island NW¼ NW¼ 25/2E-20 see Figure 29	Qw	Peat and clay interbedded within oxidized gravel unit believed to be of Olympic Mountain provenance. Correlate with unit at University Point.

REFERENCES CITED

Armstrong, J.E., Crandell, D.R., Easterbrook, D.J., and Noble, J.B., 1965, Late Pleistocene stratigraphy and chronology in southwestern British Columbia and northwestern Washington: Geol. Soc. America Bull., v. 76, p. 321-330.

Bartelli, L.J., Baird, J.V., Heddleson, M.R., and Klingebiel, A.A., 1966, Soil surveys and land use planning: Wisconsin Soil Science Society of America and American Society of Agronomy, 196 p.

Bishop, D.M., and Stevens, M.E., 1964, Landslides on logged areas in southeast Alaska: U.S.D.A. Forest Services Res. Paper, PNW-1, 18 p.

Bretz, J H., 1913, Glaciation of the Puget Sound region: Wash. Geol. Survey Bull., no. 8, 244 p.

Clapp, C.H., 1909, Southern Vancouver Island: Canada Geological Survey Summary Report, 89 p.

Crandell, D.R., 1964, Pleistocene glaciation of the southwestern Olympic Peninsula, Washington: U.S. Geol. Survey Prof. Paper 501-B, p. B135-B139.

Crandell, D.R., 1965, The glacial history of western Washington and Oregon in "The Quaternary of the United States": (Wright, H.E., and Frey, D.G., eds.), Princeton University Press, Princeton, New Jersey, p. 341-353.

Crandell, D.R., Mullineaux, D.R., and Waldron, H.H., 1958, Pleistocene sequence in southeastern part of the Puget Sound Lowland, Washington: Am. Jour. Sci., v. 256, p. 384-397.

Crandell, D.R., Mullineaux, D.R., and Waldron, H.H., 1965, Age and origin of the Puget Sound Trough in western Washington: U.S. Geol. Survey Prof. Paper 525-B, p. B132-B136.

Dorn, T.F., Fairhall, A.W., Schell, W.R., and Takashima, Y., 1962, Radiocarbon dating at the University of Washington: Radiocarbon, v. 4, p. 1-12.

Dunne, T., and Leopold, L.B., 1978, Water in Environmental Planning, San Francisco: W.H. Freeman and Co., 818 p.

Easterbrook, D.J., 1963, Late Pleistocene glacial events and relative sea level changes in the northern Puget Lowland, Washington: Geol. Soc. America Bull., v. 74, p. 1465-1484.

___________, 1968, Pleistocene stratigraphy of Island County, Washington: Washington Dept. Water Resources, Water Supply Bull. 25, p. 1-35.

___________, 1969, Pleistocene chronology of the Puget Lowland and San Juan Islands, Washington: Geol. Soc. of America Bull., v. 80, p. 2273-2286.

Easterbrook, D.J., Crandell, D.R., and Leopold, E.B., 1967, Pre-Olympia Pleistocene stratigraphy and chronology in the central Puget Lowland, Washington: Geol. Soc. America Bull., v. 78, p. 13-20.

Fullmer, C.V., 1975, Stratigraphy and paleontology of the type Blakely and Blakely Harbor Formation in "Conference on Future Energy Horizons of the Pacific Coast": A.A.P.G., S.E.P.M., and S.E.G. annual meeting, Pacific Sections Proceedings, p. 210-271.

Garling, M.E., Molenaar, Dee, Bailey, E.G., Fiedler, G.H., Russel, R.H., and Van Denburg, A.S., 1965, Water resources and geology of the Kitsap Peninsula and certain adjacent islands: Washington Division Water Resources Water Supply Bulletin 18, p. 24-50.

Hansen, B.S., and Easterbrook, D.J., 1974, Stratigraphy and palynology of late Quaternary sediments in the Puget Lowland, Washington: Geol. Soc. America Bull., v. 85, p. 587-602.

Heusser, C.J., 1972, Palynology and Phytogeographical significance of a late Pleistocene refugium near Kalaloch, Washington: Quaternary Research, v. 2, p. 189-201.

Hunt, C.B., 1972, Geology of soils, San Francisco: W.H. Freeman and Co., 344 p.

Ives, P.C., Levin, B., Oman, C.L., and Rubin, M., 1967, U.S. Geological Survey radiocarbon dates IX: Radiocarbon, v. 7, p. 505-529.

Kitsap County Dept. of Community Development, 1976, Kitsap County Shoreline Master Program, 30 p.

Levin, B., Ives, P.C., Oman, C.L., and Rubin, M., 1966, U.S. Geological Survey, radiocarbon dates VIII: Radiocarbon, v. 7, p. 372-396.

Little, Arthur D., Inc., 1974, Technical report to Kitsap County on Trident Impact, Kitsap County Dept. of Community Development, open-file, 25 p.

McMurphy, C., and Ping, C.L., in press, Soil survey of Kitsap County, Washington: U.S. Dept. of Agr., Soil Conserv. Serv., Washington Agr. Experiment Station.

Marsters, B., Spiker, E., and Rubin, M., 1969, U.S. Geological Survey radiocarbon dates X: Radiocarbon, v. 11, no. 1, p. 210-217.

Molenaar, Dee, and Noble, J.B., 1970, Geology and related groundwater occurrence, southeastern Mason County, Washington: Wash. Dept. Water Resources, Water Supply Bull. 29, p. 1-38.

Mullineaux, D.R., Waldron, H.H., and Rubin, M., 1965, Stratigraphy and chronology of late interglacial and early Vashon glacial time in the Seattle area, Washington: U.S. Geol. Surv. Bull., P. 1194-1200.

Newcomb, R.C., 1952, Groundwater resources of Snohomish County, Washington: U.S. Geol. Surv. Water Supply paper 1135, 113 p.

Rice, H.M.A., 1959, Geological Survey of Canada Map 1069 A: Victoria-Vancouver British Columbia.

Rigg, G.B., and Gould, H.R., 1957, Age of Glacier Peak eruption and chronology of post-glacial peat deposits in Washington and surrounding area: Am. Jour. Sci., v. 255, no. 5, p. 351-363.

Sceva, J.E., 1957, Geology and groundwater resources in Kitsap County, Washington: U.S. Geol. Surv. Water Supply paper 1413, 178 p.

Snyder, D.E., Gale, P.S., and Pringle, R., 1973, Soil survey of King County area, Washington: U.S. Dept. of Agr., Soil Conserv. Service, 100 p.

Stuiver, M., Heusser, C.J., and Yang, I.C., 1978, North American Glacial history extended to 75,000 years ago: Science, v. 200, p. 16-21.

Tabor, R.W., 1975, Guide to the geology of Olympic National Park: University of Washington Press, Seattle, 144 p.

U.S. Dept. of Health, Education, and Welfare, 1972, Manual of septic tank practice: Public Health Service Pub. no. 256, 92 p.

Wash. State Dept. of Social and Health Services, 1974, Rules and regulations for on-site sewage disposal systems: 11 p.

Weaver, C.E., 1912, A preliminary report on the Tertiary paleontology of western Washington: Washington Geol. Surv. Bull. 15, 80 p.

_____________, 1937, Tertiary stratigraphy of western Washington and northwestern Oregon: Washington State University Pubs. in Geology, v. 4, 266 p.